REPORT #
RRTAC 88-11

Highvale Soil Reconstruction Project: Five Year Summary

Heritage Fund

Alberta

LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee

Report No. RRTAC 88-11

Highvale Soil Reconstruction Project: Five Year Summary

by

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for

The Plains Coal Reclamation Research Program

of the

ALBERTA LAND CONSERVATION AND RECLAMATION COUNCIL
(Reclamation Research Technical Advisory Committee)

1988

DISCLAIMER

The recommendations and conclusions in this report are those of the author and not of the Alberta Government or its representatives.

This report is intended to provide government and industry staff with up-to-date technical information to assist in the preparation and review of Development and Reclamation Approvals, and development of guidelines and operating procedures. This report is also available to the public so that interested individuals similarly have access to the most current information on land reclamation topics.

ALBERTA'S RECLAMATION RESEARCH PROGRAM

Regulating surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a Chairman from Alberta Environment and two deputy chairmen from Alberta Forestry, Lands and Wildlife. The Council oversees a reclamation research program, established in 1978, to identify the most efficient methods for achieving acceptable reclamation in the province. Funding for the research program is provided by Alberta's Heritage Savings Trust Fund Land Reclamation Program.

To assist with development and administration of the research program, the Council appointed the interdepartmental Reclamation Research Technical Advisory Committee (RRTAC). The Committee consists of eight members representing the Alberta Departments of Agriculture, Forestry, Lands and Wildlife, and, Environment, and the Alberta Research Council. The Committee updates research priorities, reviews solicited and unsolicited research proposals, organizes workshops, and otherwise acts as the coordinating body for reclamation research in Alberta.

Additional information on the Reclamation Research Program may be obtained by contacting:

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RECLAMATION RESEARCH REPORTS

** 1. RRTAC 80-3: The Role of Organic Compounds in Salinization of Plains Coal Mining Sites. N.S.C. Cameron et al. 46 pp.

DESCRIPTION: This is a literature review of the chemistry of sodic mine spoil and the changes expected to occur in groundwater.

** 2. RRTAC 80-4: Proceedings: Workshop on Reconstruction of Forest Soils in Reclamation. P.F. Ziemkiewicz, S.K. Takyi, and H.F. Regier. 160 pp.

DESCRIPTION: Experts in the field of forestry and forest soils report on research relevant to forest soil reconstruction and discuss the most effective means of restoring forestry capability of mined lands.

N/A 3. RRTAC 80-5: Manual of Plant Species Suitability for Reclamation in Alberta. L.E. Watson, R.W. Parker, and D.F. Polster. 2 vols, 541 pp.

DESCRIPTION: Forty-three grass, fourteen forb, and thirty-four shrub and tree species are assessed in terms of their suitability for use in reclamation. Range maps, growth habit, propagation, tolerance, and availability information are provided.

N/A 4. RRTAC 81-2: 1980 Survey of Reclamation Activities in Alberta. D.G. Walker and R.L. Rothwell. 76 pp.

DESCRIPTION: This survey is an update of a report prepared in 1976 on reclamation activities in Alberta, and includes research and operational reclamation, locations, personnel, etc.

N/A 5. RRTAC 81-3: Proceedings: Workshop on Coal Ash and Reclamation. P.F. Ziemkiewicz, R. Stein, R. Leitch, and G. Lutwick. 253 pp.

DESCRIPTION: Presents nine technical papers on the chemical, physical, and engineering properties of Alberta fly and bottom ashes, revegetation of ash disposal sites, and use of ash as a soil amendment. Workshop discussions and summaries are also included.

N/A 6. RRTAC 82-1: Land Surface Reclamation: An International Bibliography. H.P. Sims and C.B. Powter. 2 vols, 292 pp.

DESCRIPTION: Literature to 1980 pertinent to reclamation in Alberta is listed in Vol. 1 and is also on the University of Alberta computing system (in a SPIRES database called RECLAIM). Vol. 2 comprises the keyword index and computer access manual.

N/A 7. RRTAC 82-2: A Bibliography of Baseline Studies in Alberta: Soils, Geology, Hydrology, and Groundwater. C.B. Powter and H.P. Sims. 97 pp.

DESCRIPTION: This bibliography provides baseline information for persons involved in reclamation research or in the preparation of environmental impact assessments. Materials, up to date as of December 1981, are available in the Alberta Environment Library.

N/A 8. RRTAC 83-1: Soil Reconstruction Design for Reclamation of Oil Sand Tailings. Monenco Consultants Ltd. 185 pp.

DESCRIPTION: Volumes of peat and clay required to amend oil sand tailings were estimated based on existing literature. Separate soil prescriptions were made for spruce, jack pine, and herbaceous cover types. The estimates form the basis of field trials.

N/A 9. RRTAC 83-3: Evaluation of Pipeline Reclamation Practices on Agricultural Lands in Alberta. Hardy Associates (1978) Ltd. 205 pp.

DESCRIPTION: Available information on pipeline reclamation practices was reviewed. A field survey was then conducted to determine the effects of pipe size, age, soil type, construction method, etc. on resulting crop production.

N/A 10. RRTAC 83-4: Proceedings: Effects of Coal Mining on Eastern Slopes Hydrology. P.F. Ziemkiewicz. 123 pp.

DESCRIPTION: Technical papers are presented dealing with the impacts of mining on mountain watersheds, their flow characteristics, and resulting water quality. Mitigative measures and priorities were also discussed.

N/A 11. RRTAC 83-5: Woody Plant Establishment and Management for Oil Sands Mine Reclamation. Techman Engineering Ltd. 124 pp.

DESCRIPTION: This is a review and analysis of information on planting stock quality, rearing techniques, site preparation, planting, and procedures necessary to ensure survival of trees and shrubs in oil sand reclamation.

*** 12. RRTAC 84-1: Land Surface Reclamation: A Review of the International Literature. H.P. Sims, C.B. Powter, and J.A. Campbell. 2 vols, 1549 pp.

DESCRIPTION: Nearly all topics of interest to reclamationists including mining methods, soil amendments, revegetation, propagation and toxic materials are reviewed in light of the international literature.

** 13. RRTAC 84-2: Propagation Study: Use of Trees and Shrubs for Oil Sand Reclamation. Techman Engineering Ltd. 58 pp.

DESCRIPTION: This report evaluates and summarizes all available published and unpublished information on large-scale propagation methods for shrubs and trees to be used in oil sand reclamation.

* 14. RRTAC 84-3: Reclamation Research Annual Report - 1983. P.F. Ziemkiewicz. 42 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

** 15. RRTAC 84-4: Soil Microbiology in Land Reclamation. D. Parkinson, R.M. Danielson, C. Griffiths, S. Visser, and J.C. Zak. 2 vols, 676 pp.

DESCRIPTION: This is a collection of five reports dealing with re-establishment of fungal decomposers and mycorrhizal symbionts in various amended spoil types.

** 16. RRTAC 85-1: Proceedings: Revegetation Methods for Alberta's Mountains and Foothills. P.F. Ziemkiewicz. 416 pp.

DESCRIPTION: Results of long-term experiments and field experience on species selection, fertilization, reforestation, topsoiling, shrub propagation and establishment are presented.

* 17. RRTAC 85-2: Reclamation Research Annual Report - 1984. P.F. Ziemkiewicz. 29 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

** 18. RRTAC 86-1: A Critical Analysis of Settling Pond Design and Alternative Technologies. A. Somani. 372 pp.

DESCRIPTION: The report examines the critical issue of settling pond design, and sizing and alternative technologies. The study was co-funded with The Coal Association of Canada.

** 19. RRTAC 86-2: Characterization and Variability of Soil Reconstructed after Surface Mining in Central Alberta. T.M. Macyk. 146 pp.

DESCRIPTION: Reconstructed soils representing different materials handling and replacement techniques were characterized, and variability in chemical and physical properties was assessed. The data obtained indicate that reconstructed soil properties are determined largely by parent material characteristics and further tempered by materials handling procedures. Mining tends to create a relatively homogeneous soil landscape in contrast to the mixture of diverse soils found before mining.

* 20. RRTAC 86-3: Generalized Procedures for Assessing Post-Mining Groundwater Supply Potential in the Plains of Alberta - Plains Hydrology and Reclamation Project. M.R. Trudell and S.R. Moran. 30 pp.

DESCRIPTION: In the Plains region of Alberta, the surface mining of coal generally occurs in rural, agricultural areas in which domestic water supply requirements are met almost entirely by groundwater. Consequently, an important aspect of the capability of reclaimed lands to satisfy the needs of a residential component is the post-mining availability of groundwater. This report proposes a sequence of steps or procedures to identify and characterize potential post-mining aquifers.

** 21. RRTAC 86-4: Geology of the Battle River Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze, R. Li, M. Fenton and S.R. Moran. 86 pp.

DESCRIPTION: This report summarizes the geological setting of the Battle River study site. It is designed to provide a general understanding of geological conditions adequate to establish a framework for hydrogeological and general reclamation studies. The report is not intended to be a detailed synthesis such as would be required for mine planning purposes.

** 22. RRTAC 86-5: Chemical and Mineralogical Properties of Overburden: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 71 pp.

DESCRIPTION: This report describes the physical and mineralogical properties of overburden materials in an effort to identify individual beds within the bedrock overburden that might be significantly different in terms of reclamation potential.

* 23. RRTAC 86-6: Post-Mining Groundwater Supply at the Battle River Site: Plains Hydrology and Reclamation Project. M.R. Trudell, G.J. Sterenberg and S.R. Moran. 49 pp.

DESCRIPTION: The report deals with the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is in the Battle River Mining area in east-central Alberta

* 24. RRTAC 86-7: Post-Mining Groundwater Supply at the Highvale Site: Plains Hydrology and Reclamation Project. M.R. Trudell. 25 pp.

DESCRIPTION: This report evaluates the availability of water supply in or beneath cast overburden to support post-mining land use, including both quantity and quality considerations. The study area is the Highvale mining area in west-central Alberta.

* 25. RRTAC 86-8: Reclamation Research Annual Report - 1985. P.F. Ziemkiewicz. 54 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

** 26. RRTAC 86-9: Wildlife Habitat Requirements and Reclamation Techniques for the Mountains and Foothills of Alberta. J.E. Green, R.E. Salter and D.G. Walker. 285 pp.

DESCRIPTION: This report presents a review of relevant North American literature on wildlife habitats in mountain and foothills biomes, reclamation techniques, potential problems in wildlife habitat reclamation, and potential habitat assessment methodologies. Four biomes (Alpine, Subalpine, Montane, and Boreal Uplands) and 10 key wildlife species (snowshoe hare, beaver, muskrat, elk, moose, caribou, mountain goat, bighorn sheep, spruce grouse, and white-tailed ptarmigan) are discussed. The study was co-funded with The Coal Association of Canada.

** 27. RRTAC 87-1: Disposal of Drilling Wastes. L.A. Leskiw, E. Reinl-Dwyer, T.L. Dabrowski, B.J. Rutherford and H. Hamilton. 210 pp.

DESCRIPTION: Current drilling waste disposal practices are reviewed and criteria in Alberta guidelines are assessed. The report also identifies research needs and indicates mitigation measures. A manual provides a decision-making flowchart to assist in selecting methods of environmentally safe waste disposal.

** 28. RRTAC 87-2: Minesoil and Landscape Reclamation of the Coal Mines in Alberta's Mountains and Foothills. A.W. Fedkenheuer, L.J. Knapik and D.G. Walker. 174 pp.

DESCRIPTION: This report reviews current reclamation practices with regard to site and soil reconstruction and re-establishment of biological productivity. It also identifies research needs in the Mountain-Foothills area. The study was co-funded with The Coal Association of Canada.

** 29. RRTAC 87-3: Gel and Saline Drilling Wastes in Alberta: Workshop Proceedings. D.A. Lloyd (compiler). 218 pp.

DESCRIPTION: Technical papers were presented which describe: mud systems used and their purpose; industrial constraints; government regulations, procedures and concerns; environmental considerations in waste disposal; and toxic constituents of drilling wastes. Answers to a questionnaire distributed to participants are included in an appendix.

* 30. RRTAC 87-4: Reclamation Research Annual Report - 1986. 50 pp.

DESCRIPTION: This report details the Reclamation Research Program indicating priorities, descriptions of each research project, researchers, results, and expenditures.

* 31. RRTAC 87-5: Review of the Scientific Basis of Water Quality Criteria for the East Slope Foothills of Alberta. Beak Associates Consulting Ltd. 46 pp.

DESCRIPTION: The report reviews existing Alberta guidelines to assess the quality of water drained from coal mine sites in the East Slope Foothills of Alberta. World literature was reviewed within the context of the East Slopes environment and current mining operations. The ability of coal mine operators to meet the various guidelines is discussed. The study was co-funded with The Coal Association of Canada.

** 32. RRTAC 87-6: Assessing Design Flows and Sediment Discharge on the Eastern Slopes. Hydrocon Engineering (Continental) Ltd. and Monenco Consultants Ltd. 97 pp.

DESCRIPTION: The report provides an evaluation of current methodologies used to determine sediment yields due to rainfall events in well-defined areas. Models are available in Alberta to evaluate water and sediment discharge in a post-mining situation. SEDIMOT II (Sedimentology Disturbed Modelling Techniques) is a single storm model that was developed specifically for the design of sediment control structures in watersheds disturbed by surface mining and is well suited to Alberta conditions. The study was co-funded with The Coal Association of Canada.

* 33. RRTAC 87-7: The Use of Bottom Ash as an Amendment to Sodic Spoil. S. Fullerton. 83 pp.

DESCRIPTION: The report details the use of bottom ash as an amendment to sodic coal mine spoil. Several rates and methods of application of bottom ash to sodic spoil were tested to determine which was the best at reducing the effects of excess sodium and promoting crop growth. Field trials were set up near the Vesta mine in East Central Alberta using ash readily available from a nearby coal-fired thermal generating station. The research indicated that bottom ash incorporated to a depth of 30 cm using a subsoiler provided the best results.

* 34. RRTAC 87-8: Waste Dump Design for Erosion Control. R.G. Chopiuk and S.E. Thornton. 45 pp.

DESCRIPTION: This report describes a study to evaluate the potential influence of erosion from reclaimed waste dumps on downslope environments such as streams and rivers. Sites were selected from coal mines in Alberta's mountains and foothills, and included resloped dumps of different configurations and ages, and having different vegetation covers. The study concluded that the average annual amount of surface erosion is minimal. As expected, erosion was greatest on slopes which were newly regraded. Slopes with dense grass cover showed no signs of erosion. Generally, the amount of erosion decreased with time, as a result of initial loss of fine particles, the formation of a weathered surface, and increased vegetative cover.

** 35. RRTAC 87-9: Hydrogeology and Groundwater Chemistry of the Battle River Mining Areas. M.R. Trudell, R.L. Faught and S.R. Moran. 97 pp.

DESCRIPTION: This report describes the premining geologic conditions in the Battle River coal mining area including the geology as well as the groundwater flow patterns, and the groundwater quality of a sequence of several water-bearing formations extending from the surface to a depth of about 100 metres.

** 36. RRTAC 87-10: Soil Survey of the Plains Hydrology and Reclamation Project - Battle River Project Area. T.M. Macyk and A.H. MacLean. 62 pp. plus 8 maps.

DESCRIPTION: The report evaluates the capability of post-mining landscapes and assesses the changes in capability as a result of mining, in the Battle River mining area. Detailed soils information is provided in the report for lands adjacent to areas already mined as well as for lands that are destined to be mined. Characterization of the reconstructed soils in the reclaimed areas is also provided. Data were collected from 1979 to 1985. Eight maps supplement the report.

** 37. RRTAC 87-11: Geology of the Highvale Study Site: Plains Hydrology and Reclamation Project. A. Maslowski-Schutze. 78 pp.

DESCRIPTION: The report is one of a series that describes the geology, soils and groundwater conditions at the Highvale Coal Mine study site. The purpose of the study was to establish a summary of site geology to a level of detail necessary to provide a framework for studies of hydrogeology and reclamation.

** 38. RRTAC 87-12: Premining Groundwater Conditions at the Highvale Site. M.R. Trudell and R. Faught. 83 pp.

DESCRIPTION: This report presents a detailed discussion of the premining flow patterns, hydraulic properties, and isotopic and hydrochemical characteristics of five layers within the Paskapoo Geological Formation, the underlying sandstone beds of the Upper Horseshoe Canyon Formation, and the surficial glacial drift.

* 39. RRTAC 87-13: An Agricultural Capability Rating System for Reconstructed Soils. T.M. Macyk. 27 pp.

DESCRIPTION: This report provides the rationale and a system for assessing the agricultural capability of reconstructed soils. Data on the properties of the soils used in this report are provided in RRTAC 86-2.

** 40. RRTAC 88-1: A Proposed Evaluation System for Wildlife Habitat Reclamation in the Mountains and Foothills Biomes of Alberta: Proposed Methodology and Assessment Handbook. T.R. Eccles, R.E. Salter and J.E. Green. 101 pp. plus appendix.

DESCRIPTION: The report focuses on the development of guidelines and procedures for the assessment of reclaimed wildlife habitat in the Mountains and Foothills regions of Alberta. The technical section provides background documentation including a discussion of reclamation planning, a listing of reclamation habitats and associated key wildlife species, conditions required for development, recommended revegetation species, suitable reclamation techniques, a description of the recommended assessment techniques and a glossary of basic terminology. The assessment handbook section contains basic information necessary for evaluating wildlife habitat reclamation, including assessment scoresheets for 15 different reclamation habitats, standard methodologies for measuring habitat variables used as assessment criteria, and minimum requirements for

certification. This handbook is intended as a field manual that could potentially be used by site operators and reclamation officers. The study was co-funded with The Coal Association of Canada.

** 41. RRTAC 88-2: Plains Hydrology and Reclamation Project: Spoil Groundwater Chemistry and its Impacts on Surface Water. M.R. Trudell (compiler). 135 pp.

DESCRIPTION: Two reports comprise this volume. The first "Chemistry of Groundwater in Mine Spoil, Central Alberta," describes the chemical make-up of spoil groundwater at four mines in the Plains of Alberta. It explains the nature and magnitude of changes in groundwater chemistry following mining and reclamation. The second report, "Impacts of Surface Mining on Chemical Quality of Streams in the Battle River Mining Area," describes the chemical quality of water in streams in the Battle River mining area, and the potential impact of groundwater discharge from surface mines on these streams.

** 42. RRTAC 88-3: Revegetation of Oil Sands Tailings: Growth Improvement of Silver-berry and Buffalo-berry by Inoculation with Mycorrhizal Fungi and N_2-Fixing Bacteria. S. Visser and R.M. Danielson. 98 pp.

DESCRIPTION: The report provides results of a study: (1) To determine the mycorrhizal affinities of various actinorrhizal shrubs in the Fort McMurray, Alberta region; (2) To establish a basis for justifying symbiont inoculation of buffalo-berry and silver-berry; (3) To develop a growing regime for the greenhouse production of mycorrhizal, nodulated silver-berry and buffalo-berry; and, (4) To conduct a field trial on reconstructed soil on the Syncrude Canada Limited oil sands site to critically evaluate the growth performance of inoculated silver-berry and buffalo-berry as compared with their uninoculated counterparts.

** 43. RRTAC 88-4: Plains Hydrology and Reclamation Project: Investigation of the Settlement Behaviour of Mine Backfill. D.R. Pauls (compiler). 135 pp.

DESCRIPTION: This three part volume covers the laboratory assessment of the potential for subsidence in reclaimed landscapes. The first report in this volume, "Simulation of Mine Spoil Subsidence by Consolidation Tests," covers laboratory simulations of the subsidence process particularly as it is influenced by resaturation of mine spoil. The second report, "Water Sensitivity of Smectitic Overburden: Plains Region of Alberta," describes a series of laboratory tests to determine the behaviour of overburden materials when brought into contact with water. The report entitled "Classification System for Transitional Materials: Plains Region of Alberta," describes a lithological classification system developed to address the characteristics of the smectite rich, clayey transition materials that make up the overburden in the Plains of Alberta.

** 44. RRTAC 88-5: Ectomycorrhizae of Jack Pine and Green Alder: Assessment of the Need for Inoculation, Development of Inoculation Techniques and Outplanting Trials on Oil Sand Tailings. R.H. Danielson and S. Visser. 177 pp.

DESCRIPTION: The overall objective of this research was to characterize the mycorrhizal status of Jack Pine and Green Alder which are prime candidates as reclamation species for oil sand tailings and to determine the potential benefits of mycorrhizae on plant performance. This entailed determining the symbiont status of container-grown nursery stock and the quantity and quality of inoculum in reconstructed soils, developing inoculation techniques and finally, performance testing in an actual reclamation setting.

* 45. RRTAC 88-6: Reclamation Research Annual Report - 1987. Reclamation Research Technical Advisory Committee. 67 pp.

DESCRIPTION: This annual report describes the expenditure of $500,000.00 of Alberta Heritage Savings Trust Fund monies on research under the Land Reclamation Program. The report outlines the objectives and research strategies of the four program areas, and describes the projects funded under each program.

* 46. RRTAC 88-7: Baseline Growth Performance Levels and Assessment Procedure for Commercial Tree Species in Alberta's Mountains and Foothills. W.R. Dempster and Associates Ltd. 66 pp.

DESCRIPTION: Data on juvenile height development of lodgepole pine and white spruce from cut-over or burned sites in the Eastern Slopes of Alberta were used to define reasonable expectations of early growth performance as a basis for evaluating the success of reforestation following coal mining. Equations were developed predicting total seedling height and current annual height increment as a function of age and elevation. Procedures are described for applying the equations, with further adjustments for drainage class and aspect, to develop local growth performance against these expectations. The study was co-funded with The Coal Association of Canada.

** 47. RRTAC 88-8: Alberta Forest Service Watershed Management Field and Laboratory Methods. A.M.K. Nip and R.A. Hursey, Alberta Forest Service. 4 Sections, various pagings.

DESCRIPTION: Disturbances such as coal mines in the Eastern Slopes of Alberta have the potential for affecting watershed quality during and following mining. The collection of hydrometric, water quality and hydrometeorologic information is a complex task. A variety of instruments and measurement methods are required to produce a record of hydrologic inputs and outputs for a watershed basin. There is a growing awareness and recognition that standardization of data acquisition methods is required to ensure data comparability, and to allow comparison of data analyses. The purpose of this manual is to assist those involved in the field of data acquisition by outlining methods, practices and instruments which are reliable and recognized by the International Organization for Standardization.

** 48. RRTAC 88-9: Computer Analysis of the Factors Influencing Groundwater Flow and Mass Transport in a System Disturbed by Strip Mining. F.W. Schwartz and A.S. Crowe, SIMCO Groundwater Research Ltd. 78 pp.

DESCRIPTION: Work presented in this report demonstrates how a groundwater flow model can be used to study a variety of mining-related problems such as declining water levels in areas around the mine as a result of dewatering, and the development of high water tables in spoil once resaturation is complete. This report investigates the role of various hydrogeological

parameters that influence the magnitude, timing, and extent of water level changes during and following mining at the regional scale. The modelling approach described here represents a major advance on existing work.

* 49. RRTAC 88-10: D.R. Pauls, S.R. Moran and T. Macyk, 1988. Review of Literature Related to Clay Liners for Sump Disposal of Drilling Wastes. 61 pp.

DESCRIPTION: The report reviews and analyses the effectiveness of geological containment of drilling waste in sumps. Of particular importance was the determination of changes in properties of clay materials as a result of contact with highly saline brines containing various organic chemicals.

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** A $10.00 fee is charged for handling and postage.
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N/A Not available for purchase but available for review at the Alberta Environment Library, 14th Floor, 9820 - 106 Street, Edmonton, Alberta T5K 2J6

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ACKNOWLEDGEMENTS

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1. The Heritage Savings Trust Fund which provided financial support through the Land Surface Conservation and Reclamation Council.

2. TransAlta Utilities Corporation who provided initial plot construction funding and heavy equipment for the ongoing maintenance of the plots and adjacent areas.

3. The Steering Committee, Plant-Soil, Groundwater and Geochemistry Sub-Committees of the Reclamation Research Technical Advisory Committee and the Alberta Environment Research Management Divisions' Project Manager, Mr. C.B. Powter, for their continued guidance and assistance on all aspects of the project.

4. All advisors, especially Mr. M. Davidson of TransAlta Utilities for his onsite assistance and those at the Univeristy of Alberta, including Dr. D. Chanasyk of the Department of Soil Science for the use of their facilities for calibration of the neutron probe and Dr. Z. Kondra of the Department of Plant Science for his input regarding crop establishment.

The key Monenco personnel involved in this project were:

1. Mr. L.A. Panek - responsible for project management, field coordination, final report review and quality control.

2. Mr. T.A. Oddie - responsible for all field related agricultural activities, statistical data analysis, depth experiment write-up and report preparation.

3. Mr. A.E. Osborne - responsible for statistical data analysis, slope experiment write-up and report preparation.

4. Mr. D. Graveland - responsible for overall report review.

5. Dr. J.R. Dean - responsible for the laboratory analytical component.

6. Mr. E.C. Wenzel - responsible for field moisture and bulk density monitoring, soil sampling, climatological data acquisition, computer data management and SAS run input.

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ABSTRACT

The Highvale Soil Reconstruction Project was initiated in 1982 by government and coal industry representatives to provide interpretive data for reclamation planning and post-mine land management of sodic strip-mined soils. The project objectives were to: 1) determine the optimum depth of subsoil replacement over sodic minespoil to ensure adequate crop productivity; 2) examine slope configurations which could minimize soil quantities needed to restore the original productivity of reclaimed land; and 3) assess the sustainability of crop production on soil replaced over sodic minespoil by monitoring upward soluble salt migration into the root zone.

A subsoil depth experiment was established to determine suitable subsoil thicknesses (0.00, 0.55, 0.95, 1.35, 1.85 and 3.45 m underlying 0.15 m topsoil) for reclaiming sodic minespoil and maximizing production of an annual barley cereal crop or a perennial alfalfa-smooth bromegrass forage mixture. A slope experiment was established to determine the effects of slope types (5° and 10° slopes, north and south aspects) and slope positions (lower, mid and upper) on alfalfa-smooth bromegrass forage crop productivity. Soil water movement, salt/sodium migration, and bulk density were monitored throughout both experiments.

For the subsoil depth experiment, crop yields increased as subsoil thickness increased from 0.00 to 0.55 m, while optimum yields were generally achieved with the replacement of at least 0.95 m subsoil. The forage crop developed a deeper effective root zone, had better root penetration into minespoil and reduced soil bulk density more than the barley crop. Soil moisture levels above the subsoil/minespoil interface tended to decline over time under forage,

likely due to higher consumptive use of soil moisture compared to the barley crop. The potential for moisture accumulation above the interface when seeded to barley may enhance upward migration of soluble sodium, although movement has generally been limited to the first 15 cm increment above minespoil after five years. For the slope experiment, forage yield was generally highest on north-facing aspects, 5° slopes and mid to upper slope positions. There was no consistent trend in downslope migration of soluble sodium, likely due to utilization of soil moisture by the forage crop. Upward migration of soluble sodium was similar to the suboil depth experiment.

1. INTRODUCTION

1.1 BACKGROUND

One of Alberta's great natural resources is coal. There are an estimated 81 billion tonnes of potentially recoverable coal in Alberta. Slightly more than 90 percent of the potentially recoverable coal is found in the Plains region (Webb 1982).

Much of the coal underlies Plains soils suitable for agriculture. Agriculture is the prime use for at least 47 percent of the total coal field acreage in Alberta. Approximately 530,000 hectares of the total land overlying minable coal is arable (class 1 to 4) (Webb 1982).

Strip mining is the method of choice for coal deposits situated near the surface under flat landscapes as is the case in Alberta. A large strip mine will ultimately disturb thousands of hectares and is highly visible if left unreclaimed. Webb (1982) observed that only a small fraction, approximately 10%, of the potential strip mine hectares are now under approved coal leases. He noted that ten percent of the leased lands had been reclaimed by 1982.

Reclamation of all lands disturbed by mining is now manditory as spelled out in Alberta's Land Surface Conservation and Reclamation Act (RSA 1980, cL-3). However, reclamation technology is still young.

Full reclamation of soils is difficult because many changes in the physical characteristics of the soil result from the mining process. Strip mining reduces the capacity of soils to accumulate water. Reclaimed soils are often subject to erosion by slumping, piping and runoff. Erosion of soils results in reduced soil productivity, and makes the establishment of new plant communities difficult. Reclamation is made particularly difficult when saline and sodic spoil materials end up near the soil surface after the mine pits have been refilled (Webb 1982). The latter topic is the subject of the remainder of this report.

1.2 LITERATURE REVIEW

The successful return of strip mined land to productive use depends, in part, on the physical and chemical characteristics of the minespoil and the depth of suitable root zone material. Research in the Plains region of North America has shown that the two most important soil properties for crop growth that can be modified by changes in the soil environment during reclamation are water infiltration/ retention and sodicity/soluble salt levels (Doll et al. 1984). Minespoil sodicity causes clay particles to disperse, which reduces pore size and restricts movement of soil air and water (Smith et al. 1985; Uresk and Yamamato 1986). Research shows that when minespoil has properties that restrict plant growth and thereby impede reclamation success, sufficient topsoil and/or suitable subsoil should be salvaged and replaced over minespoil to help restore reclaimed land to pre-mine crop productivity levels (Hargis and Redente 1984). Soil reconstruction can be accomplished by carefully removing each soil layer prior to mining and then replacing this material in proper sequence during site reclamation.

The benefits of topsoil replacement over sodic minespoil have been reported by a number of researchers in North Dakota and Montana. Topsoil replacement alone has been shown to increase crop yields and improve water use efficiency within the soil profile (Halvorson et al. 1987; Sieg et al. 1983). Merrill et al. (1983a), working in North Dakota, showed that an application of only 30 cm of topsoil over moderately sodic (SAR of 12) and highly sodic (SAR of 27) minespoil increased forage yields by 25 and 84%, respectively, compared to an 8% increase over non-sodic minespoil. Power et al. (1976), also working in North Dakota, reported that as little as 5 cm of topsoil over very sodic minespoil was beneficial to plant growth, but noted that at least 70 cm was required to maximize crop production. Their research showed no additional benefit when more than 70 cm of topsoil was applied, and reduced benefits when topsoil was mixed into minespoil. The reduced benefit of mixed topsoil and

minespoil was also noted by Fresquez and Lindemann (1983) working in New Mexico. They observed, however, that the incorporated topsoil was effective in improving organic matter content, increasing minespoil fertility, and stimulating microbial activity. Additional benefits of topsoil application that have been reported include increases in water infiltration, greater root penetration, and increased crop yields (Chong et al. 1986; McGinnies and Nicholas 1980; Rimmer and Gildon 1986; Schuman et al. 1985).

Subsoil underlying topsoil has also proven beneficial in reclaiming sodic minespoil and restoring productivity in North Dakota and Alberta (McAllister Environmental Services Limited, 1985; Pedology Consultants Limited, 1987; Power et al. 1979). Barth and Martin (1984) showed that about 70 cm total soil thickness provided maximum forage grass yields over sodic minespoil (SAR's from 25 to 81) in Wyoming, Montana and North Dakota. Power et al. (1981) reported an increase in yield and root depth in North Dakota for several crops as subsoil thickness increased. Their results showed that when sodic minespoil (SAR of 25) occurred within 90 and 150 cm of the surface, water extraction could be observed to a soil depth of: 135 and 175 cm respectively under alfalfa; 120 and 150 cm respectively under crested wheatgrass; 80 and 120 cm respectively under native grasses; and 75 and 90 cm respectively under spring wheat. No accumulations of soil moisture above the subsoil/minespoil contact were observed under any crop treatment. Merril et al. (1985) and Power et al. (1985) both reported maximum forage grass yields in North Dakota on 20 cm topsoil plus 80 cm subsoil over sodic minespoil (SAR of 30). They showed that root depth and the amount of soil water extracted increased as subsoil thickness increased. They noted that low hydraulic conductivity in sodic minespoil had an inhibitory effect on plant growth by limiting water use.

Upward migration of sodium from sodic minespoil can deteriorate the quality of replaced topsoil or subsoil and reduce post-mine crop productivity (Merrill et al. 1980). Accumulations of sodium in

subsoil have been observed immediately above the minespoil contact by a number of researchers examining reclaimed mined land (Merrill et al. 1983b; Scholl 1987). The researchers noted that the diffusion rate of sodium was slow and that the potential for overlying soil degradation would not likely occur unless there was less than 30 cm of non-sodic soil present and the SAR of the minespoil was greater than 20. Redente et al. (1982) and Stark and Redente (1986) showed that utilization of a 30 cm gravel barrier between minespoil and overlying soil material resulted in the prevention of sodium migration from sodic Colorado oil shale (SAR of 14) into subsoil and significantly increased crop growth.

Reduced permeability at the subsoil/minespoil contact can also contribute to accumulations of soil moisture above the contact. A higher moisture content in subsoil overlying less permeable sodic minespoil increases the efficiency of upward sodium migration, such as through diffusion or convection (Merrill et al. 1983a). The higher moisture content of subsoil overlying minespoil also has the potential to reduce surface access by agricultural farm machinery if very moist soil conditions can not be controlled by crop evapotranspiration or soil internal drainage.

By 1980 the majority of the literature available for review originated from the Great Plains region of the western United States. The Soils Advisory Committee of Alberta Agriculture, upon review of the available literature, came to the interim conclusion that there was a minimum depth of suitable soil material that should be salvaged before strip mining, stockpiled and then replaced during reclamation. Data from North Dakota sited by Webb (1982) suggested "that at least 1.5 metres of suitable soil be replaced if available." Monenco Limited (1982) reviewed the conditions at Highvale and recommended the replacement of 1.2 metres of soil material (where available) over sodic minespoils. Other researchers suggested a minimum of 3.0 metres of suitable soil replacement (Graveland 1978).

Alberta Agriculture (1981) recognized a replacement target for reclamation success of 3.0 metres as a total depth of suitable replacement material over sodic minespoil. The authors went on to define the material to be replaced as topsoil ("A" horizon of the the soil profile), subsoil ("B" horizons and upper portion of the parent material to a depth of 1.15 metres), and a buffer zone (material between the root zone and bedrock or sodic spoil).

Unfortunately, the more often materials have to be handled or the greater the quantities of materials to be moved, the greater the cost of mining. Reclamation costs in 1981 were estimated to range from $400 to $9,000 per hectare (Webb 1982).

In view of the large potential areas of agricultural land with sodic bedrock to be disturbed by strip mine operations, high reclamation costs, uncertainty on replacement depths, and lack of information for industry operators, the Alberta Government sponsored research on coal strip mine reclamation of soils which are underlain by saline and/or sodic parent materials. One of these research programs, the Highvale Soil Reconstruction Project, is the subject of this report.

1.3 PROJECT HISTORY AND LOCATION

The main objective of the coal strip mine soil reclamation research in Alberta, has been to identify physical and chemical limitations to land reclamation and define reclamation guidelines for minimizing the impact of soil disturbances. The envisioned guidelines, if implemented, would return disturbed land to at least its former level of capability (Land Conservation and Reclamation Council et al. 1977).

Over the past several years at the Highvale Mine west of Edmonton, the focus of reclamation research has been on the selection of a suitable thickness of subsoil for forage and cereal crop production. The effect of steepness of slope and aspect under a given subsoil regime have also been examined. Subsurface moisture and salt/

sodium movement above sodic minespoil under various subsoil treatments and in four slope configurations were key factors of concern.

In order to obtain information on these factors which ultimately affect reclamation success, the Alberta Government, electric utilities and the coal industry initiated the Highvale and Battle River Soil Reconstruction Projects. This report presents a summary of the activities and results of the reclamation research project at the Highvale Mine for a five year (1983 to 1987) monitoring period.

Experimental plots were established in 1982 at the Highvale Mine in order to provide interpretive data for reclamation planning and post-mining land management. Two sets of experimental plots were constructed to monitor soil and crop parameters. These parameters were considered vital to the sustained production of agricultural crops under different subsoil depth and slope configuration conditions. The experimental plots were located on a post mine landscape within the Highvale Mine Permit Area which is situated 65 km west of Edmonton (Sec. 7, Twp 52, Rge 4-W5) as shown on Figure 1.

TransAlta Utilities Corporation provided construction funding for the research plots. Monenco Consultants Limited supervised the plot construction as well as selection, sampling and analyses of topsoil, subsoil and minespoil.

The subsequent monitoring programs, including those discussed in this report, are funded from the Heritage Savings Trust Fund through the Land Conservation and Reclamation Council. The monitoring program involved the measurement of a number of experimental plot parameters including crop yield, root depth, soil moisture and bulk density levels during the growing season, pH, electrical conductivity, soluble cations, chloride and sulfate.

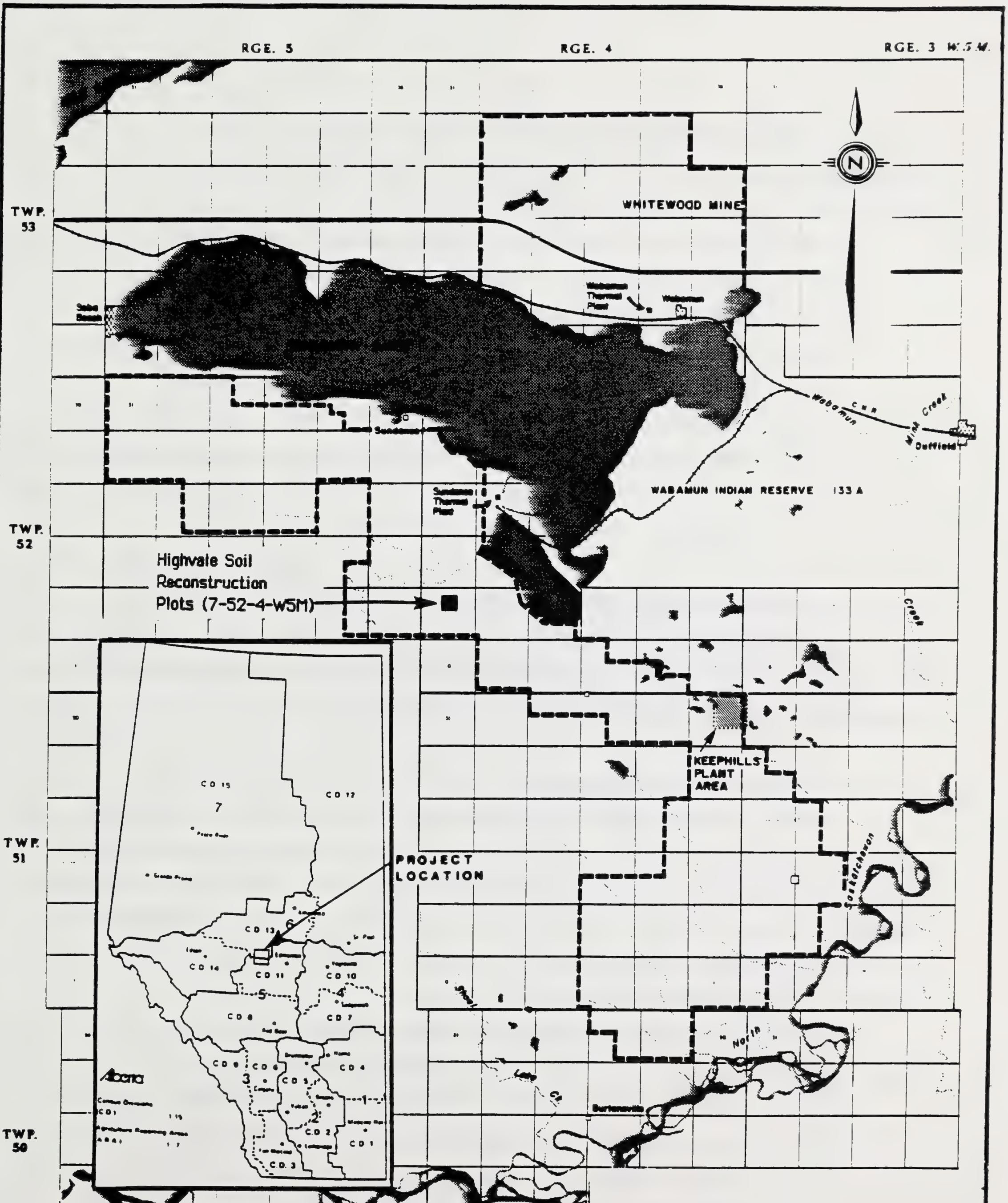


FIGURE 1
ALBERTA ENVIRONMENT
HIGHVALE SOIL RECONSTRUCTION PROJECT
PROJECT LOCATION MAP

1.4 GENERAL PROJECT OBJECTIVES

The general objectives of the subsoil depth and slope experiments were as follows:

1. Determine an optimum depth of subsoil replacement over sodic minespoil to ensure adequate crop productivity;
2. Examine treatments and slope configurations which could minimize soil quantities needed to restore the original productivity of reclaimed lands.
3. Establish a productive agricultural soil and assess the sustainability of crop production over sodic minespoil by monitoring upward soluble salt migration from sodic minespoil into the crop root zone;

1.5 SPECIFIC EXPERIMENTAL OBJECTIVES AND HYPOTHESES

The subsoil depth and slope experiments were each designed to test certain null hypotheses. The specific objectives and hypotheses for each experiment are outlined below.

1.5.1 Subsoil Depth Experiment

The subsoil depth experiment was established in order to provide information that could help in the selection of an optimum depth of subsoil replacement material over sodic minespoil. The dynamics of soil moisture and the vertical distribution of sodium in surface, subsoil, and minespoil materials were monitored under a cereal and forage crop regime.

A number of null hypotheses were tested over the course of the five year research program. These hypotheses were:

1. Crop productivity on reclaimed sodic minespoil will not be a function of subsoil thickness (subsoil was defined as non-sodic soil material placed between minespoil and replaced topsoil). If rejected, identify optimum subsoil thickness.

2. Forage and grain crops will not respond differently to varying subsoil thickness. If rejected, identify optimum subsoil thickness for each crop.
3. The subsoil/minespoil interface will not interfere with vertical movement of water. If rejected, quantify the effect.
4. Sodium will not migrate upward from sodic minespoil into overlying subsoil. If rejected, quantify the effect.

The 0.00 m subsoil treatment involved the application of topsoil directly over sodic minespoil.

1.5.2 Slope Experiment

Post-mining topographic configurations depend upon the degree of minespoil levelling. It was postulated before experimental plot construction that aspect and degree of slope could affect soil moisture migration, moisture storage, sodium movement, and crop productivity. In turn, these factors could determine the long term potential productivity of reclaimed land. The major objective of the slope drainage experiment was to quantify the relationships between topographic configuration and crop productivity, water movement and sodium migration. The null hypotheses defined for this experiment were as follows:

1. Downslope sodium transport will be independent of slope and aspect. If rejected, quantify the effect.
2. Crop productivity will not be a function of slope position, slope steepness or aspect in the reclaimed landscape. If rejected, quantify the effect of slope position, slope steepness and aspect.

1.6 PROJECT SETTING

1.6.1 Climate Data and Growing Season

The study area was located within the Dry Subhumid Climatic Zone 2 (Bowser 1967). Climate Zone 2 is suitable for the production of a variety of crops without major risk of frost damage (Lindsay et al. 1968). There are approximately 100 frost-free days in the growing season (May 9 to September 11), which restricts the type of crops that can be grown to forages and short season cereal and oilseed crops (Chapman and Brown, 1978). There are about 1350 growing degree days above 5°C.

The potential moisture deficit for a grass crop in the Highvale Mine area is approximately 50 mm (Canada Department of Transport 1978). The potential moisture deficit for a cereal crop is less than 50 mm. The growing season precipitation may exceed the potential consumptive use of a cereal crop.

1.6.2 Geology and Soils

Approximately one to seven metres of unconsolidated clay till, laminated lacustrine silty clay and fragments of weathered shale and coal overlay undisturbed bedrock in the north half of the Highvale Mine Permit Area. The depth of these unconsolidated deposits reaches 50 metres in the south Highvale Permit Area (Collins and Swan 1955).

The coal bearing strata underlying the surficial lacustrine and till materials belong to the Tertiary Period Scollard Member of the Edmonton Formation. The bedrock is both freshwater and marine in origin (Gibson 1977). The influx of the sea water which occurred during the Tertiary Period has given the bedrock at Highvale its sodic characteristics (Moran and Cherry 1977).

The bedrock types that make up the coal field are sandstone, shale and siltstone. The partings between the coal seams have a high

proportion of clay and characteristically contain high sodium concentrations.

The soils within the Highvale Mine Permit Area reflect the nature of underlying parent materials. The soils have developed on one of eight parent materials; sodic till, sodic displaced bedrock, non-sodic till, non-sodic displaced bedrock, slopewash, alluvium, glacio-lacustine, and organic materials.

Approximately forty percent of the north Highvale Mine Area is dominated by Solonetzic soils such as Kavanagh, Thorsby, Nakamun and Namepi which have developed on sodic till and displaced bedrock. Most Solonetzic soils have a neutral to acidic A horizon and a B horizon that is very hard when dry and swells to a sticky mass of very low permeability when wet. Solonetzic soils pose moderate to severe physical limitation to the plant root zone.

The remaining soils are developed on non-sodic parent materials and include soil series representing primarily soils of the Luvisolic, Gleysolic, Brunisolic, and Organic Orders.

1.6.3 Soil Capability and Crop Yields

Soil capability in the Project Area is not rated above Class 3 due to limitations of climate, topography, soil structure and drainage. Approximately 20% of the mine area is rated Class 3, 37% is rated Class 4, 35% is rated Class 5 and 8% is rated Class 6 or unsuitable for agriculture (TransAlta Utilities Corporation 1986).

Ten year (1978 to 1987) average barley yields of 2.3 tonnes/hectare (52.8 bu/ac) have been reported for Census Division 11 (Keir Packer, Alberta Agriculture, pers. comm. 1988). Average forage yields of 4.7 tonnes/hectare have been reported for Agricultural Reporting Area 5 (Census Division 8 and 11).

1.6.4 Land Use and Cropping Practices

Two-thirds of the land in the Highvale Mine Permit area (Figure 1) is in agricultural use. Prior to mining (1971)

approximately 53% of the north Highvale Permit Area was cultivated for annual grains, forage and improved pasture. The remaining 47% was unmanaged pasture and brush land used for rough grazing.

By 1985, 49% of the north Highvale Mine area was devoted to cereal grains, forage, and pasture. Unmanaged rough grazing land covered 35% of the area. Seventeen percent of the area was devoted to mining, generating plants, and reclaimed land (TransAlta Utilities Corporation 1986).

2. METHODS AND MATERIALS

2.1 EXPERIMENTAL DESIGN AND PLOT CONSTRUCTION

The Subsoil Depth Experiment and Slope Drainage Experiment were established in 1982. Both experiments were constructed of topsoil and subsoil taken from the same borrow site located adjacent to the mined plot-site. The chemical and physical characteristics of the topsoil, subsoil and minespoil materials are shown in Table 1 and discussed in Section 2.2. Although plot construction materials were similar, construction procedures varied between experiments.

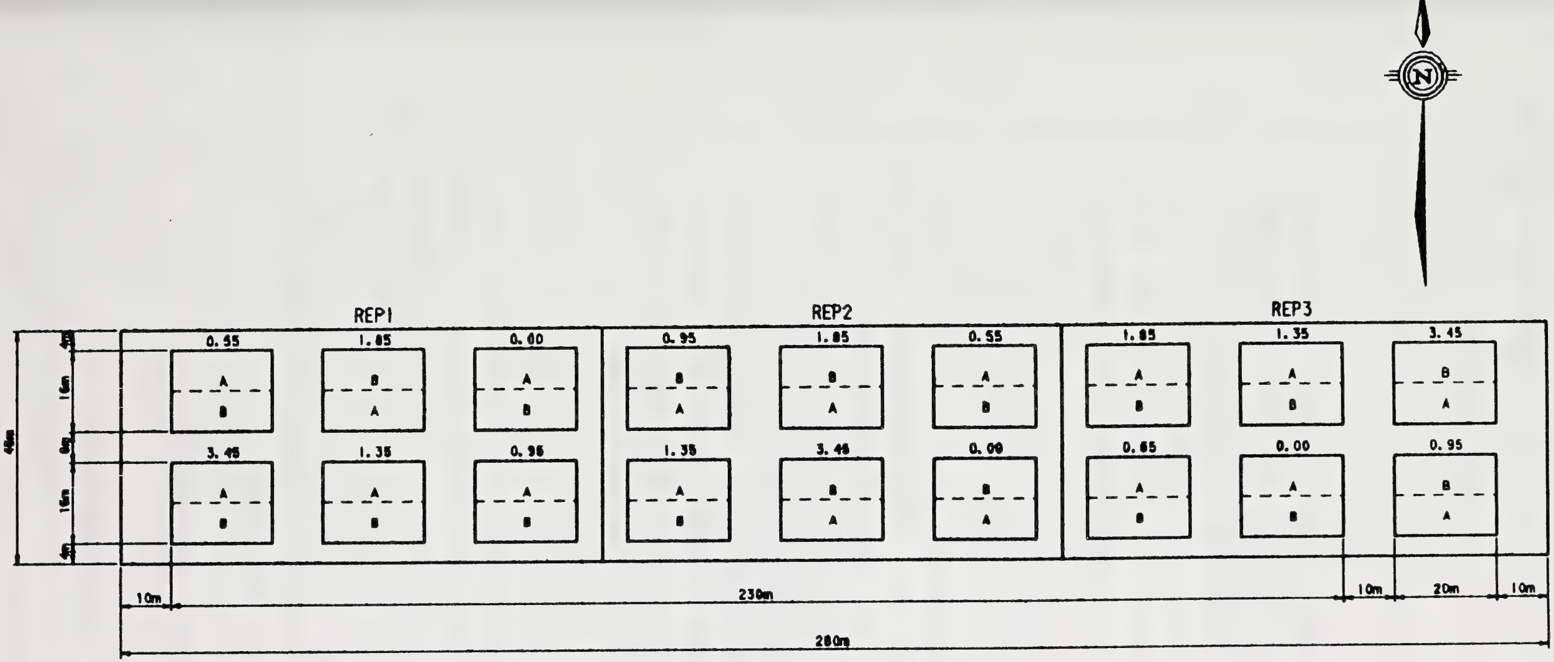
2.1.1 Subsoil Depth Experiment

The experimental design was a "split-plot" (Cochran and Cox 1957) consisting of six subsoil thicknesses randomized in main-plots, two crops randomized in split-plots and three replications of each treatment. The initial plan called for subsoil thicknesses of 0.0, 0.25, 0.50, 1.00, 1.50 and 3.00 meters. To compensate for anticipated settling, additional subsoil material was added to each treatment at the time of construction. However, actual subsidence was considerably less than anticipated. As a result, actual treatment depths were 0.00, 0.55, 0.95, 1.35, 1.85 and 3.45 metres underlying 0.15 m of topsoil. The experimental layout is shown in Figure 2.

Subsoil depth plot construction was executed first by excavating into leveled minespoil to the required depth. The exposed sides of the excavated pits were lined with plastic. The plastic was installed to restrict lateral movement of moisture and sodium from the adjacent sodic minespoil once clean subsoil had been backfilled. Each main plot measured 16 m wide x 20 m long. Subsoil was added and packed until level with the surface, then topsoil was applied. The experimental area was graded to allow drainage away from each plot.

Table 1. Properties of topsoil, subsoil and minespoil materials used for plot construction in 1982.

Soil Property	Material		
	Topsoil	Subsoil	Minespoil
Texture	Clay Loam	Silty Clay	Sandy Clay Loam
pH	7.2	7.7	8.5
Saturation (%)	57	57	95
EC_e (mS/cm)	0.6	0.5	1.9
Soluble Na (me/L)	0.6	0.9	14.4
Soluble K (me/L)	0.9	0.3	0.3
Soluble Ca (me/L)	4.6	3.3	1.1
Soluble Mg (me/L)	1.1	0.9	0.3
Soluble Cl (me/L)	0.5	0.3	0.2
Soluble SO_4 (me/L)	0.8	0.8	10.7
SAR	0.4	0.7	20.1



A - ALFALFA (RAMBLER) AND BROMEGRASS (CARLTON)
B - BARLEY (KLONDIKE)
0.00 NO SUBSOIL
0.55 0.55m SUBSOIL
0.95 0.95m SUBSOIL
1.35 1.35m SUBSOIL
1.95 1.95m SUBSOIL
3.45 3.45m SUBSOIL

FIGURE 2

ALBERTA ENVIRONMENT
HIGHVALE SOIL RECONSTRUCTION PROJECT
SUBSOIL DEPTH EXPERIMENT
LAYOUT

2.1.2 Slope Experiment

The experimental design was a "split-block" (Little and Hills 1978) consisting of four slope types in main plots, three slope positions in sub-plots and three incomplete randomized replications. The main-plots consisted of combinations of slope steepness (5° and 10°) and slope aspect (North and South). Subplots included slope positions identified as lower, mid and upper slope. The experimental layout is shown in Figure 3.

The plots were formed by pushing minespoil into the required slope aspect and steepness. Subsoil was then spread over the minespoil to a depth of 0.60 m, then covered with 0.15 m of topsoil. Each main-plot measured 24 m wide x 38 m long. The experimental area was graded to allow drainage away from each lower slope position.

2.2 BASELINE SOIL AND MINESPOIL INFORMATION

A soil survey of the borrow pit area showed soils of the Dark Gray Luvisol and Orthic Humic Regosol subgroups. Weathered residual bedrock material and till were the primary parent materials.

The topsoil collected from the borrow area had a clay loam texture, neutral reaction (pH = 7.2) and was non-saline (EC_e = 0.6 mS/cm) and non-sodic (SAR = 0.4). The subsoil was silty clay textured, slightly alkaline in reaction (pH = 7.7), non-saline (EC_e = 0.5 mS/cm) and non-sodic (SAR = 0.7). The minespoil was of a sandy clay loam texture, non-saline (EC_e = 1.9 mS/cm), alkaline in reaction (pH = 8.5) and sodic (SAR = 20.1). Based on these parameters, the suitability of material for reclamation can be generally rated as good (topsoil), fair to good (subsoil) and fair to unsuitable (minespoil) for the Plains region (Alberta Agriculture 1987).

2.3 CROP ESTABLISHMENT AND ANNUAL MAINTENANCE

2.3.1 Site Preparation After Plot Construction

The plots were left over the winter to settle. The following spring glyphosate herbicide (Roundup) was applied (May 25,

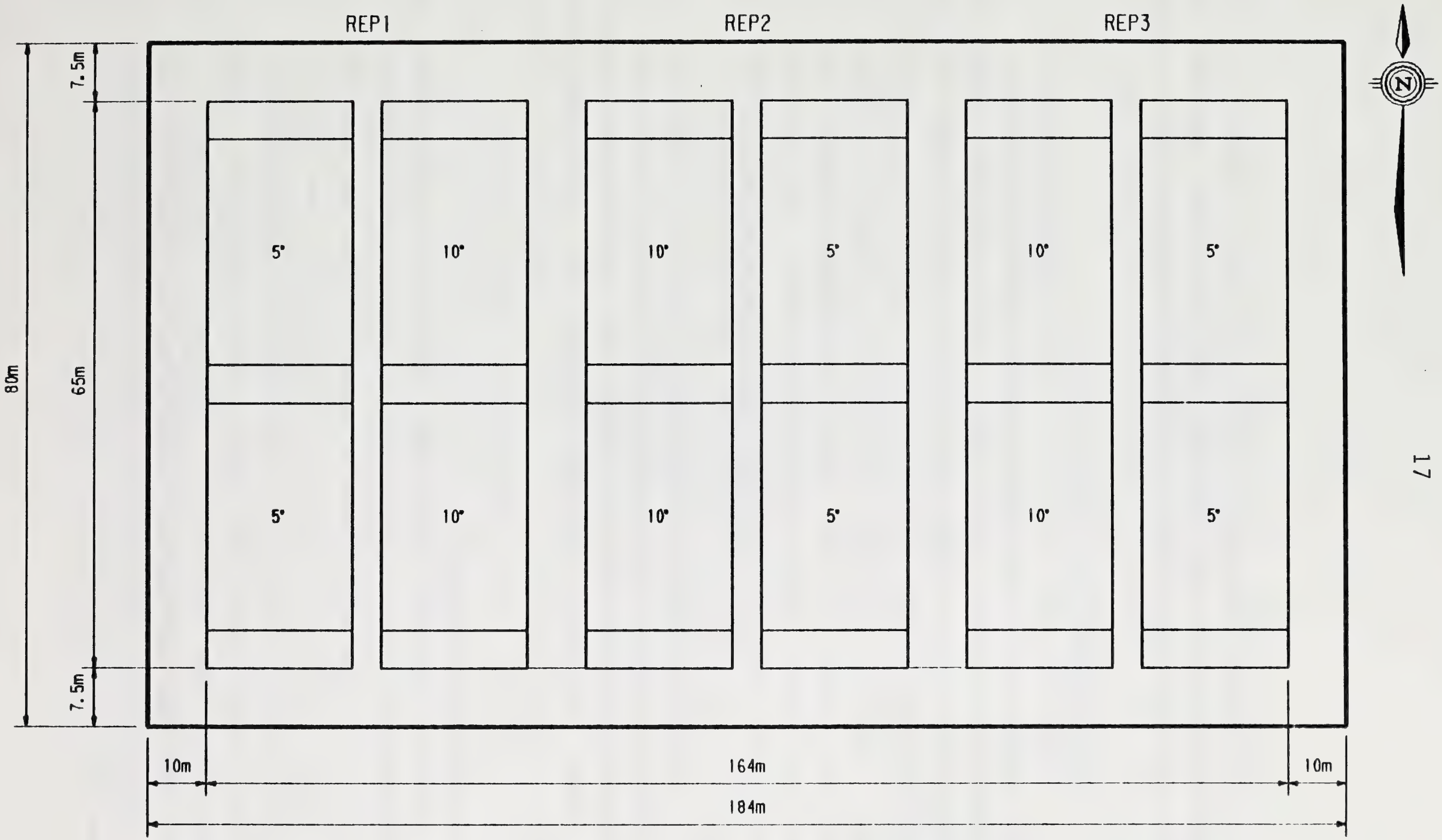


FIGURE 3
ALBERTA ENVIRONMENT
HIGHVALE SOIL RECONSTRUCTION PROJECT
SLOPE EXPERIMENT
LAYOUT

1983) to kill existing vegetation and prepare the site for cultivation and seeding. The plots were cultivated three times (early June) to break up sod-bound clumps. Roots and rocks were removed by hand.

2.3.2 Annual Weed and Pest Control Program

Annual weed growth was controlled by mechanical and chemical measures, such as spring cultivations prior to seeding, hand weeding, and herbicide applications, as required. Herbicide applications to the barley crop included: MCPA-amine on July 19, 1983; no herbicide in 1984; Bromoxynil + MCPA on June 2, 1985; Buctryl M on July 7, 1986; Hoegrass II on May 27, 1987 and MCPA-amine on July 14, 1987. Herbicide applications to the forage crop included Embutox-E on July 20, 1983 during forage seedling establishment. All herbicide applications were made at recommended rates using a tractor mounted sprayer.

A severe grasshopper infestation in 1985 necessitated two applications of Malathion (July 30, August 6). Waterfowl depredation caused reduced grain yields on the 0.00 m subsoil depth treatment in 1984. Wire productivity cages and scarecrows were set up as a deterrent in subsequent years.

2.3.3 Fertilizer Program

Annual fertilizer applications were based on spring soil fertility analysis. Composite samples from each treatment and subplot were analyzed for available N-P-K-S in topsoil (0-15 cm) and available N-S in subsoil (15-30 cm). Fertilizer recommendations were based on information provided by the Alberta Soil and Feed Testing Laboratory. Fertilizer was applied by disk and/or broadcast applicator during late-May to early-June each year.

Fertilizer applications to the barley crop included: 62 kg N/ha and 17 kg P/ha in 1983; 17 kg N/ha and 17 kg P/ha in 1984; 34 kg N/ha and 17 kg P/ha in 1985; 75 kg N/ha in 1986 and 75 kg N/ha in 1987.

Fertilizer applications to the forage crop included: 50 kg N/ha and 11 kg P/ha in 1983; 50 kg N/ha and 17 kg P/ha in 1984; 50 kg N/ha and 11 kg P/ha in 1985; 56 kg N/ha in 1986; and 28 kg N/ha and 17 kg S/ha in 1987.

2.3.4 Seeding Program

'Klondike' barley (*Hordeum vulgare*) was drill seeded into the subsoil depth plots in May of each year at a rate of 108 kg/ha. 'Rambler' alfalfa (*Medicago sativa*) and 'Carlton' smooth bromegrass (*Bromus inermis*) were seeded into the subsoil depth experiment plots and the slope plots with a Brillion seeder on June 8, 1983 at a rate of 8 and 20 kg/ha, respectively.

2.3.5 Observations and Plot Maintenance

Grasshopper and geese depredation created concerns in some years. Lodging was observed on all barley plots in August, 1987. The alfalfa component of forage vegetation established on the 0.00 m depth treatment decreased over time, but did not generally change on the other treatments. The interplot areas were mowed on a monthly schedule to control weeds.

Minespoil failure threatened the subsoil depth plots in 1985. A portion of the north east corner of the subsoil plot gave way and destroyed the north half of subplot #16A (1.35 metre treatment, forage subplot, replicate 3). The plot was reconstructed and reseeded that year.

2.4 DATA COLLECTION AND ANALYSIS

2.4.1 Meteorological Data Collection

Meteorological information has been collected since 1978 at the Keephills Meteorological Station (located about six kilometres east of the study site). The annual data for average daily temper-

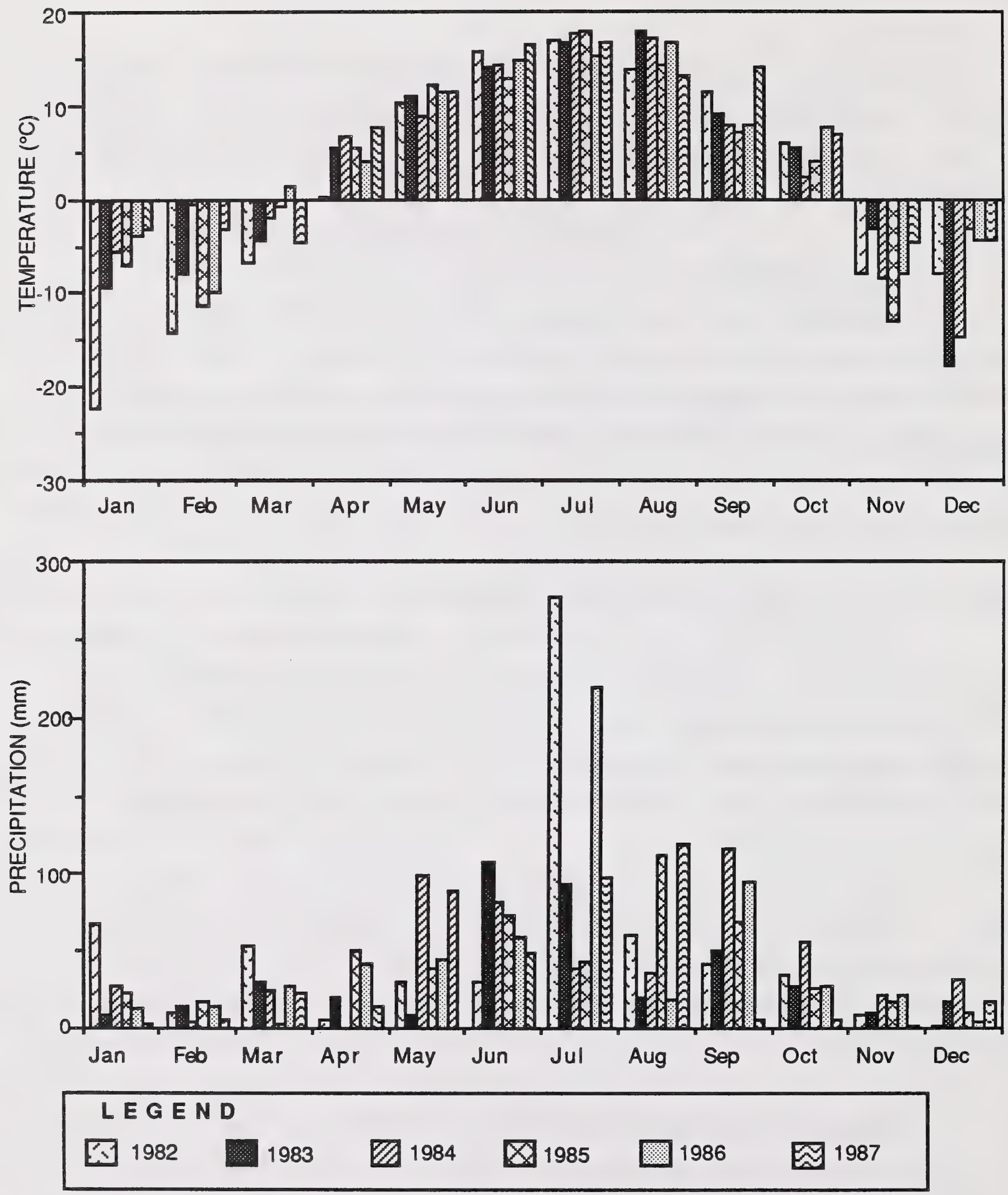


Figure 4. Average monthly temperature (^{o}C) and precipitation (mm) for the years 1982 to 1987 recorded at the Keephills Meteorological Station.

ature (°C) and total monthly precipitation (mm) for each of the experimental years (1982 to 1987) has been summarized in Figure 4.

Annual precipitation totalled 620 mm in 1982, 406 mm in 1983, 536 mm in 1984, 482 mm in 1985, 585 mm in 1986 and 431 mm in 1987. The average annual precipitaton for the six year period was 510 mm, while the ten year (1978 to 1987) average was 538 mm. The mean daily temperature was 1.3°C in 1982, 3.1°C in 1983, 3.7°C in 1984, 3.3°C in 1985, 4.5°C in 1986 and 5.6°C in 1987. The ten year (1978 to 1987) mean daily temperature was 3.6°C.

The mean daily temperature during the growing season (April to October) was 11.4°C in 1983; 10.7°C in 1984; 10.6°C in 1985; 11.2°C in 1986; and 12.3°C in 1987. Precipitation during the growing season (April to October) totalled 326 mm in 1983; 428 mm in 1984; 411 mm in 1985; 506 mm in 1986; and 382 mm in 1987.

2.4.2 Soil Moisture and Bulk Density Monitoring

Soil moisture (% by volume) and bulk density were measured on a monthly basis throughout the growing season (April to October) with a Model 501 Campbell Pacific Nuclear Depth Probe. Average seasonal soil moisture (April - October) was calculated to assess moisture depletion by crop treatments over each monitoring period. Annual neutron probe calibrations were completed against a dual gamma ray probe at the University of Alberta farm (Nakayama and Reginato 1982). Annual statistical correlations between the two instrument readings of r^2=0.69 to r^2=0.92 were reported. In addition, a regression analysis showed that gravimetric moisture readings converted to neutron probe equivalents for subsoil by the following equation:

$$\text{Depth Probe Moisture} = 0.95\ (\text{gravimetric}) + 9.86$$

Two neutron probe access tubes were installed in each split-plot of the depth experiment, while only one tube was installed in each subplot of the slope experiment. The access tubes were installed to a depth of 50 cm below the subsoil/minespoil contact

position (Howse 1981). Measurements were conducted at 15 cm intervals. Data were manually recorded and stored in the 501 DR data logger and transmitted from the field to the Calgary data terminal. The recorded soil bulk density measurements were corrected for moisture content to derive dry bulk density values.

2.4.3 Crop Harvesting Program

Crop yields were determined by clipping two randomly selected 1 m^2 areas (10 m^2 in 1983 only) from the central portion of each plot at 5 cm above ground level. Annual forage samples were clipped from the same areas in late June to early July and again in mid-September. Due to forage establishment in 1983 and a dry fall in 1984, only one harvest was collected in these years. The forage samples were oven-dried after each harvest and weighed. Grain samples were clipped in late August to early September, air dried, threshed and weighed. Conversion to tonnes/hectare was calculated as $0.01 \times g/m^2$.

2.4.4 Soil Sampling Program

2.4.4.1 Subsoil Depth Experiment. After the fall crop harvest, the topsoil, subsoil and minespoil was sampled at 15 to 30 cm increments for physical inspection and chemical analyses. Two randomly selected sites were sampled in each split-plot. Samples were taken to the same depth of minespoil in each depth treatment. Root abundance and depth of penetration were noted from drill cores extracted in 1985, 1986 and 1987. Plant root abundance was determined in terms of none, very few, plentiful and abundant (Canada Soil Survey Committee 1978).

2.4.4.2 Slope Drainage Experiment. The procedure for sampling soils in the slope drainage plots was the same as that described in section 2.4.4.1.

2.4.5 Soil Chemical Analyses

The soil chemical analyses were performed on air dried samples for the following parameters: pH, EC_e, SAR and soluble Na, K, Ca, Mg, Cl and SO_4. Analyses were performed on saturated paste extracts following McKeague (1978). The three point hydrometer method (McKeague 1978) was used to determine soil texture during plot construction. The results were entered on computer disc at the laboratory and transferred to the Monenco mainframe Digital Vax computer system. Laboratory quality control was checked by analyses of a known standard sample after each batch of 15 field samples.

2.4.6 Statistical Analyses

Crop yield, root depth, soil moisture, bulk density and soil chemistry data collected in the year of plot construction and over the five year experimental period were analyzed statistically using a split-plot (subsoil depth experiment) and split-block (slope experiment) analysis of variance procedure (5% level of significance). The statistical analyses also generated means, standard deviation, standard error of the mean, coefficient of variability and linear trend analyses. A Duncan's multiple comparison of means was used to compare differences between measured parameters among treatments, materials (at critical depths) and years. The Statistical Analysis System (S.A.S.) software package was used to carry out the statistical analyses (SAS Institute Inc. 1985). All data were retained in hard copy.

The large size of the plots made replication difficult and costly. Compromises were reached, early in the plot design, between conflicting goals of a demonstration and research program. Replicate variability, due to the small number of replicates and lack of soil uniformity under field plot conditions, contributed to reduced sensitivity of the statistical analysis. Therefore, apparent differences in parameter mean values were not always significantly different. The confidence limits (95%) assigned to this experiment are considered conservative for a project of this type.

3. RESULTS

3.1 INTRODUCTION

This section of the report contains results of crop yield, root depth, soil moisture, bulk density and soil chemistry data compiled from 1982 to 1987. Throughout the remaining text of this report, data analysis for specific soil parameters has been summarized for 'critical' zones, including:

1. The effective subsoil root zone. This is a highly variable characteristic which differs among plants with changing soil moisture conditions. The effective root zone generally accounts for 80% or more of the total water removed from the soil by combined evaporation and transpiration. Using root depth and soil moisture measurements, the effective subsoil root zone was defined as 15-85 cm for barley and 15-185 cm for forage. Only the subsoil root zone was measured due to variation in minespoil sodicity and permeability. Therefore, the effective root zone ended at the minespoil contact for shallow subsoil treatments. The effective root zone for these experiments closely matched the effective rooting depth for grain (90 cm) and alfalfa (180 cm) noted by Hausenbuiller (1985).
2. The subsoil/minespoil interface. This zone was defined as the 15 cm increment immediately above the subsoil/minespoil contact. This zone was considered 'critical' due to the potential for early detection of upward migration of salts/sodium from the underlying minespoil and reduced permeability at the contact.

3.2 SUBSOIL DEPTH EXPERIMENT

3.2.1 Crop Yield

3.2.1.1 Crop Yield Between Subsoil Thicknesses. A comparison of mean annual forage and barley (grain) yields between subsoil thicknesses has been summarized in Table 2 and Figure 5. Forage and barley yields were lower on the 0.00 m subsoil treatment than all other subsoil treatments over the 5 year period. Crop yields for barley and forage increased as subsoil thickness increased to 0.55 m, with a trend towards achieving optimum yield when subsoil thickness increased to 0.95 m. However, the increase in yield on the 0.55 m to 0.95 m treatment was not significant at the 95% confidence level. There was generally very little increase in crop yield when more than 0.95 m of subsoil was applied (i.e., 1.35, 1.85 or 3.45 m). In fact, there was a trend toward decreasing yields on the 3.45 m subsoil treatment compared to 0.95, 1.35 and 1.85 m.

3.2.1.2 Crop Yield Between Years. A comparison of annual forage and barley (grain) yields between years has been summarized in Table 3. Forage yields were lower in 1983 during crop establishment than all other years. There was no significant difference in annual forage yields measured between 1984, 1985, 1986 or 1987. Barley yields were more variable from year to year, with higher mean yields in 1985 than 1983, 1986 or 1987, and lowest yields in 1984.

3.2.2 Root Depth Observations

3.2.2.1 Root Depth Between Subsoil Thicknesses. A comparison of the annual root depth observations (depth of maximum root penetration as noted in drill logs) between subsoil thicknesses has been summarized in Table 4 and Figure 6. Forage root depth increased as subsoil thickness increased from 0.00 m to 1.35 m treatment. Average forage

Table 2. Comparison of annual barley (grain) and forage[a] yields[b] between subsoil thicknesses - subsoil depth experiment.

Subsoil Thickness (m)	Year 1983	1984	1985	1986	1987	5 Year Mean
	Forage Yield (g/m^2) (n=6)					
0.00	68c	384a	423a	467a	264b	321b
0.55	146ab	483a	524a	473a	486a	422a
0.95	186a	640a	516a	533a	513a	478a
1.35	125b	597a	553a	530a	529a	467a
1.85	136ab	597a	552a	556a	509a	470a
3.45	136ab	572a	501a	531a	494a	447a
S.E.	22	98	68	70	75	42
	Barley Yield (g/m^2) (n=6)					
0.00	112b	7b	154b	197a	205b	135b
0.55	284a	149a	401a	305a	250ab	278a
0.95	293a	176a	462a	336a	323a	318a
1.35	344a	188a	455a	276a	313a	315a
1.85	327a	176a	453a	342a	291a	318a
3.45	318a	171a	381a	331a	291a	298a
S.E.	36	42	54	47	33	23

[a] Forage = oven dry weight (total yields); Barley = air dry grain weight.

[b] Mean yields down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

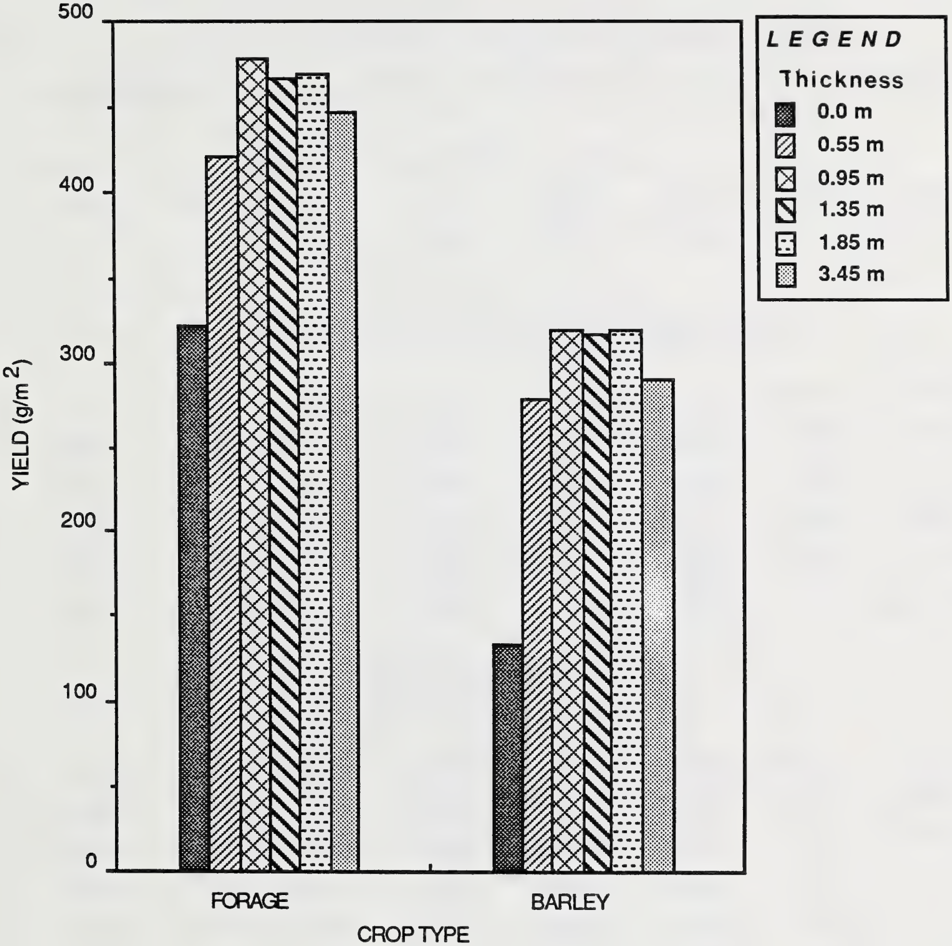


Figure 5. Comparison of 5 year mean barley (grain) and forage yields (g/m ^{2}) between subsoil treatments - subsoil depth experiment.

Table 3. Comparison of forage[a] and annual barley (grain) yields between years - subsoil depth experiment.

Year	Subsoil Thickness						Mean
	0.00m	0.55m	0.95m	1.35m	1.85m	3.45m	
	Forage Yield[b] (g/m^2) (n=6)						
1983	68c	146b	186a	125b	136b	136a	133b
1984	384a	483a	640a	597a	597a	572a	546a
1985	423a	524a	516a	553a	552a	501a	511a
1986	467a	473a	533a	530a	556a	531a	515a
1987	264b	486a	513a	529a	509a	494a	466a
S.E.	37	90	23	56	117	32	35
	Barley Yield (g/m^2) (n=6)						
1983	112ab	284b	293b	344b	327ab	318a	280b
1984	7b	149c	176c	188d	176c	171b	144c
1985	154a	401a	462a	455a	453a	381a	384a
1986	197a	305b	336b	276c	342ab	331a	298b
1987	205a	250b	323b	313bc	291bc	291a	279b
S.E.	48	39	40	27	57	43	22

a Forage = oven dry weight; Barley = air dry grain weight.

b Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

Table 4. Comparison of annual rooting depths between subsoil thicknesses within crops - subsoil depth experiment.

Subsoil Thickness (m)	Approximate SS/MS[a] Contact (m)	Year 1985	Year 1986	Year 1987	3 Year Mean
		Rooting Depth[b] (m)			
		Forage (n=6)			
0.00	0.15	0.50c	0.60e	0.60d	0.57e
0.55	0.70	0.63c	0.82de	0.93c	0.79d
0.95	1.10	0.95b	1.02cd	1.33b	1.10c
1.35	1.50	1.54a	1.29bc	1.46b	1.43b
1.85	2.00	1.63a	1.79a	1.46b	1.59ab
3.45	3.60	1.58a	1.59ab	1.79a	1.66a
S.E.		0.12	0.17	0.14	0.08
		Barley (n=6)			
0.00	0.15	0.40a	0.37a	0.40a	0.39a
0.55	0.70	0.45a	0.47a	0.55a	0.49a
0.95	1.10	0.58a	0.58a	0.66a	0.61a
1.35	1.50	0.60a	0.58a	0.61a	0.60a
1.85	2.00	0.67a	0.65a	0.78a	0.70a
3.45	3.60	0.63a	0.58a	0.69a	0.63a
S.E.		0.11	0.12	0.12	0.10

[a] SS = Subsoil; MS = Minespoil.

[b] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

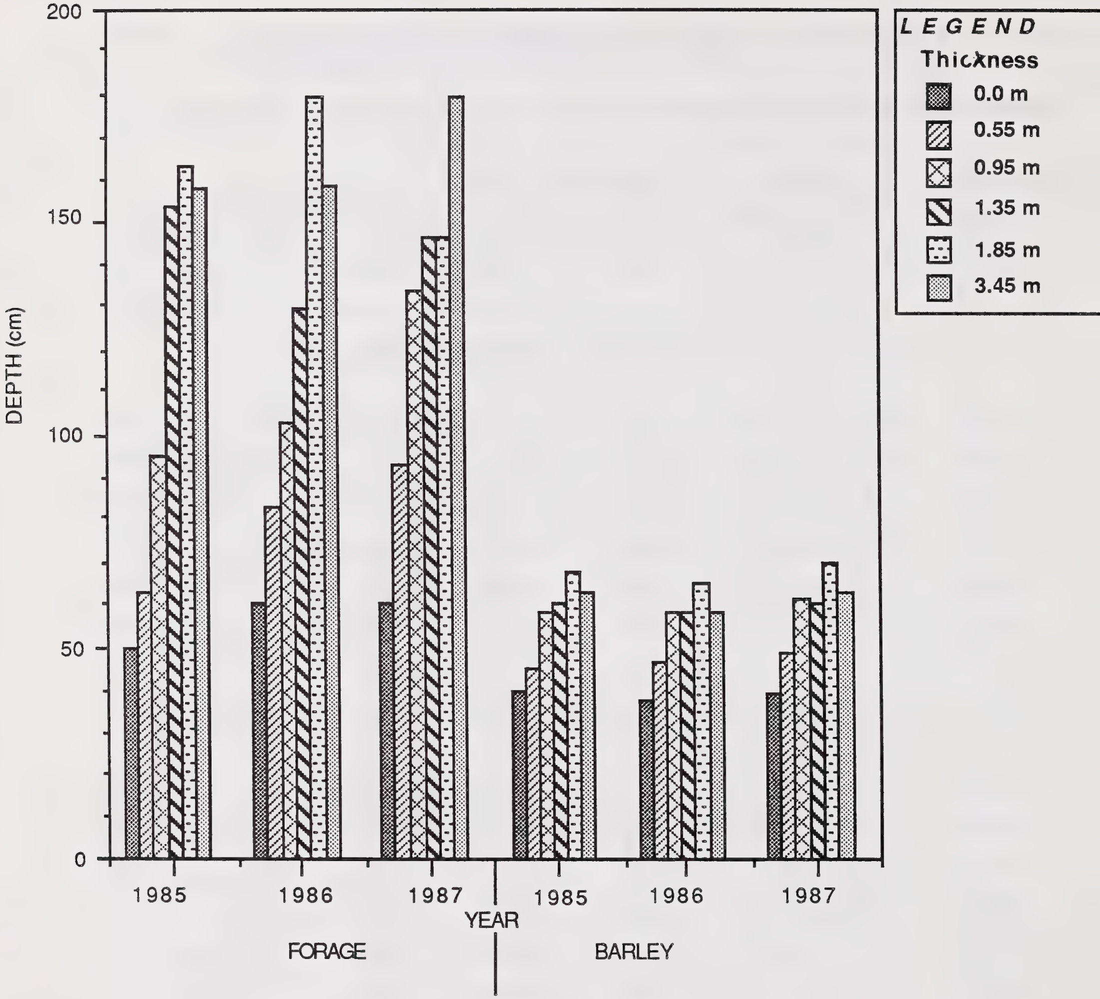


Figure 6. Comparison of annual rooting depths (cm) between subsoil treatments within the forage and barley subplots - subsoil depth experiment.

root depth was 0.57 m on the 0.00 m subsoil treatment, indicating average penetration into minespoil of about 0.42 m. Root penetration into minespoil on the 0.55 and 0.95 m treatments was 0.09 and 0.00 m, respectively. Roots were not observed in minespoil with thicker subsoil.

A trend toward increasing barley root depth was observed as subsoil thickness increased from 0.00 to 0.95 m (Table 4). Average root depth was 0.39 m on the 0.00 m barley subsoil treatment, indicating average penetration into minespoil of about 0.24 m. Root penetration into minespoil was not observed in any thicker subsoil treatments under barley.

The results show that roots of both crop types were able to penetrate minespoil that was near the surface. This may be the result of weathering of the shallow minespoil, which would improve soil structure and thus increase the effective root zone.

3.2.3 Soil Moisture

3.2.3.1 Soil Moisture Between Subsoil Thicknesses. A comparison of average seasonal (April to October) soil moisture (%) between subsoil thicknesses for the 15 cm increment above the subsoil/minespoil contact has been summarized in Table 5. Soil moisture content above the subsoil/minespoil contact did not vary under the forage crop in 1983, but was reduced at the contact in the 0.55, 0.95 and 1.35 m subsoil treatments in 1984, 1985 and 1986. By 1987, soil moisture was reduced above the subsoil/minespoil contact in the 0.55, 0.95, 1.35 and 1.85 m subsoil treatments. Considering this information and root depth observations, the effective root zone was considered to extend to about 1.85 m by 1987. Averaged over the five years, soil moisture declined above the subsoil/minespoil contact in the 0.55, 0.95 and 1.35 m treatments.

Soil moisture content above the subsoil/minespoil contact did not generally differ between treatments under barley in any year

Table 5. Comparison of average growing season subsoil moisture content between subsoil thicknesses within crops for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

Subsoil Thickness (m)	Year 1983	1984	1985	1986	1987	5 Year Mean
			Soil Moisture[a] (%)			
			Forage (n=42[b])			
0.55	32.2a	26.7b	26.3b	27.3b	26.4bc	27.4b
0.95	32.3a	27.4b	27.6b	26.4b	26.6bc	27.5b
1.35	34.4a	26.7b	25.2b	24.9b	24.6c	26.4b
1.85	33.5a	32.5a	36.2a	32.7a	30.9b	33.0a
3.45	31.8a	32.0a	37.7a	35.2a	36.5a	34.9a
S.E.	0.8	1.4	1.6	1.9	1.9	1.2
			Barley (n=42)			
0.55	31.6a	29.7a	33.2b	33.7a	34.1a	32.5a
0.95	32.4a	30.3a	34.5b	34.1a	36.4a	33.6a
1.35	32.6a	31.5a	35.7ab	35.5a	38.3a	34.8a
1.85	29.6a	30.3a	33.1b	32.3a	35.1a	32.2a
3.45	33.3a	32.2a	38.0a	35.9a	37.7a	35.7a
S.E.	1.1	1.3	1.2	1.3	1.6	1.1

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

[b] Two tubes per sub-plot x 3 replicates x 7 readings/year.

(Table 5). There was a slight trend, however, toward higher soil moisture above the subsoil/minespoil contact in the 1.35 m and 3.45 m subsoil treatments under barley. Soil moisture measurements and root depth observations indicated an effective rootzone of about 85 cm under barley.

3.2.3.2 Soil Moisture Between Crops. A comparison of average seasonal subsoil moisture (%) between crops for the 15 cm increment above the subsoil/minespoil contact has been summarized in Table 6. Soil moisture above the contact was generally higher under barley than forage in the 0.55, 0.95 and 1.35 m subsoil treatments from 1984 to 1987. Soil moisture appeared higher under barley than forage in the 1.85 m subsoil treatment in 1987 only. There were no statistical differences in soil moisture between crops for the 3.45 m treatment.

3.2.3.3 Soil Moisture Between Years. A comparison of average seasonal subsoil moisture (%) between years for the 15 cm increment above the subsoil/minespoil contact has been summarized in Table 7 and Figure 7. Soil moisture levels above the contact have generally decreased over time under forage. There was a decrease in soil moisture under forage in the 1.35 m subsoil treatment between 1983 to 1984, with a similar decreasing trend in the 0.55 and 0.95 m treatments. Soil moisture levels above the contact appeared to decrease in the 1.85 m treatment by 1987 and increase over time in the 3.45 m treatment.

Soil moisture levels above the contact generally increased over time for each subsoil treatment under barley (Table 7). Over all treatments, soil moisture was lowest in 1984 and then tended to increase until 1987.

A comparison of average seasonal root zone moisture (%) between years has been summarized in Table 8. The root zone moisture status has significantly decreased over the past five years under forage on the 0.95 and 1.35 m treatment, and shows a trend (although

Table 6. Comparison of average growing season subsoil moisture content between crops within subsoil thicknesses for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

Crop	Year 1983	1984	1985	1986	1987	5 Year Mean
	Subsoil Moisture[a] %					
	0.55m Subsoil Treatment (n=42)					
Forage	32.2a	26.7a	26.3b	27.3b	26.4b	27.4b
Barley	31.6a	29.7a	33.2a	33.7a	34.1a	32.5a
S.E.	0.6	0.9	1.3	1.6	1.2	0.9
	0.95m Subsoil Treatment (n=42)					
Forage	32.3a	27.4a	27.6a	26.4a	26.6b	27.5a
Barley	32.4a	30.3a	34.5a	34.1a	36.4a	33.6a
S.E.	0.8	1.5	2.9	2.7	2.4	1.8
	1.35m Subsoil Treatment (n=42)					
Forage	34.4a	26.7a	25.2b	24.9a	24.6a	26.4b
Barley	32.6a	31.5a	35.7a	35.5a	38.3a	34.8a
S.E.	0.7	1.4	1.0	0.2	0.1	0.4
	1.85m Subsoil Treatment (n=42)					
Forage	33.5a	32.5a	36.2a	32.7a	30.9a	33.0a
Barley	29.6b	30.3a	33.1a	32.3a	35.1a	32.2a
S.E.	0.3	1.7	1.7	1.8	2.2	1.3
	3.45m Subsoil Treatment (n=42)					
Forage	31.8a	32.0a	37.7a	35.2a	36.5a	34.8a
Barley	33.3a	32.2a	38.0a	35.9a	37.7a	35.7a
S.E.	1.0	0.2	1.2	0.3	0.6	0.6

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

Table 7. Comparison of average growing season subsoil moisture content between years within crops for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

Year	Subsoil Thickness 0.55m	0.95m	1.35m	1.85m	3.45m	Mean
	Soil Moisture[a] (%)					
	Forage (n=42)					
1983	32.2a	32.3a	34.4a	33.5a	31.8a	32.8a
1984	26.7a	27.4a	26.7b	32.5a	32.0a	29.1c
1985	26.3a	27.6a	25.2b	36.2a	37.7a	30.5b
1986	27.3a	26.4a	24.9b	32.7a	35.2a	29.3c
1987	26.4a	26.6a	24.6b	30.9a	36.5a	29.0c
S.E.	0.7	1.1	1.2	0.7	0.3	0.5
	Barley (n=42)					
1983	31.6b	32.4a	32.6a	29.6d	33.3a	32.0c
1984	29.7c	30.3a	31.5a	30.3cd	32.2a	30.7d
1985	33.2ab	34.5a	35.7a	33.1ab	38.0a	34.8b
1986	33.7a	34.1a	35.5a	32.3bc	35.9a	34.3b
1987	34.1a	36.4a	38.3a	35.1a	37.7a	36.3a
S.E.	0.7	0.7	0.4	0.8	0.3	0.3

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

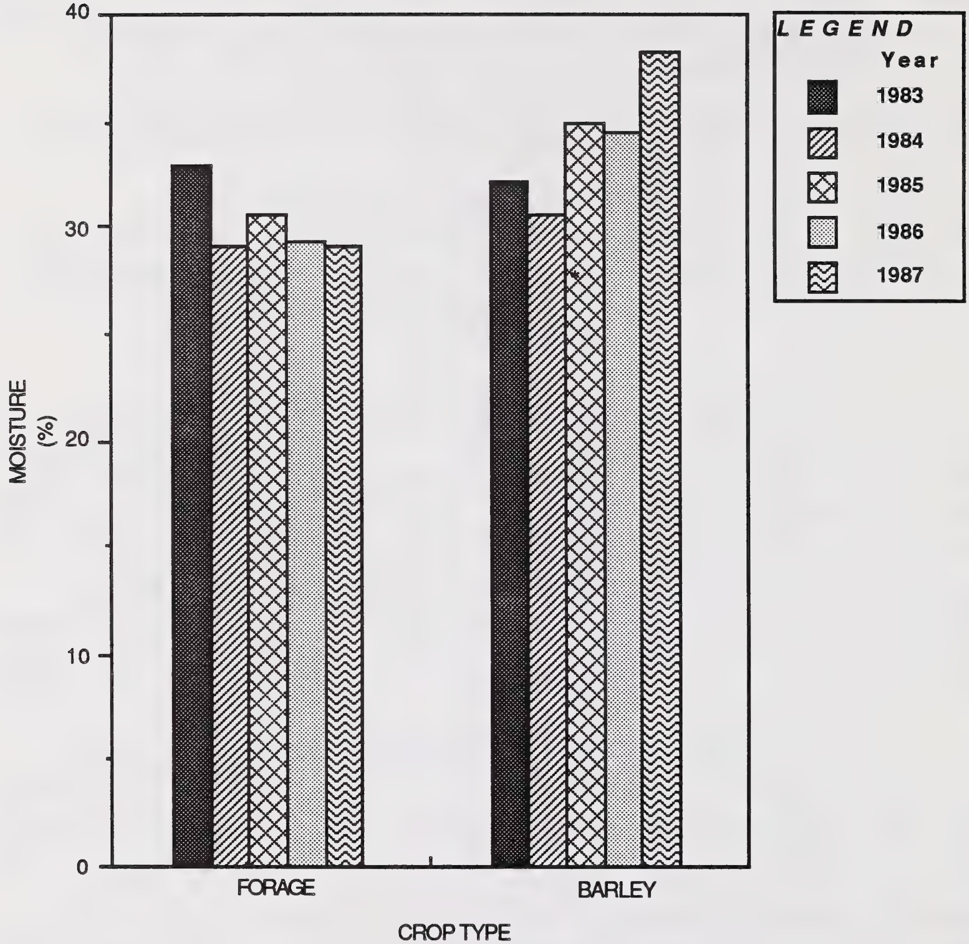


Figure 7. Comparison of average seasonal soil moisture content (%) between years within the forage and barley subplots for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

Table 8. Comparison of average growing season subsoil moisture content between years within subsoil thicknesses for the effective subsoil root zone[a] - subsoil depth experiment.

Year	Subsoil Thickness 0.55m	0.95m	1.35m	1.85m	3.45m	5 Year Mean
	Soil Moisture[a] (%)					
	Forage (effective root zone = 15 to 185 cm)(n = 18 to 72)					
1983	31.6a	31.8a	31.2a	31.8a	32.0a	31.7
1984	26.4a	25.4b	25.4b	27.0a	27.5a	26.3
1985	25.9a	25.0b	24.7bc	27.2a	29.4a	26.4
1986	27.3a	26.1b	24.0cd	26.4a	28.3a	26.4
1987	26.0a	25.1b	22.9d	25.5a	27.5a	25.4
S.E.	0.52	0.76	0.71	0.36	0.44	
	Barley (effective root zone = 15 to 85 cm)(n = 18 to 30)					
1983	30.7b	31.2a	30.3a	30.9a	31.0b	30.8
1984	29.4c	28.5a	27.3a	29.2a	28.7c	28.6
1985	32.8a	32.5a	31.7a	33.1a	33.8a	32.8
1986	33.2a	33.5a	32.2a	33.2a	34.0a	33.2
1987	33.0a	33.8a	32.9a	33.9a	34.2a	33.6
S.E.	0.52	0.51	0.32	0.39	0.40	

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

not statistically significant) to decreased moisture levels over time in all other treatments. The trend for the cereal crops has been towards an increase in moisture status over time. After the 5 year trial period the differential in moisture between the two subplots is approximately 8%. Additional information on soil moisture within the root zone has been reported by Oddie and Bailey (1988).

3.2.4 Soil Bulk Density

3.2.4.1 Soil Bulk Density Between Subsoil Thicknesses. A comparison of October soil dry bulk density between subsoil thicknesses within the effective root zone has been summarized in Table 9. There were no differences in bulk density between treatments and no identifiable trends under forage or barley in any year.

3.2.4.2 Soil Bulk Density Between Crops. A comparison of October soil dry bulk density between crops for the effective root zone has been summarized in Table 10. Bulk density was consistently higher under barley than forage in the 1.35 m subsoil treatment (after forage establishment in 1983). A similar trend was evident in all other subsoil thicknesses.

3.2.4.3 Soil Bulk Density Between Years. A comparison of October soil dry bulk density between years for the effective root zone has been summarized in Table 11 and Figure 8. There was a decrease in mean subsoil bulk density over time for subsoil treatments under forage, while the subsoil bulk density under barley increased.

3.2.5 Soil Chemistry

3.2.5.1 Soil Chemistry Between Subsoil Thicknesses. A comparison of soil chemistry (Electrical Conductivity or EC_e, soluble Na, Sodium Adsorption Ratio or SAR) parameters between subsoil thicknesses for

Table 9. Comparison of October soil dry bulk density between subsoil thicknesses within the forage and barley subplots for the effective subsoil root zone[a] - subsoil depth experiment.

Subsoil Thickness (m)	Year 1983	1984	1985	1986	1987	5 Year Mean
	Dry Bulk Density[b] (g/cc)					
	Forage (n=18 to 72[c])					
0.55	1.30	1.34	1.15	1.25	1.21	1.25
0.95	1.30	1.24	1.16	1.21	1.20	1.22
1.35	1.30	1.26	1.17	1.20	1.21	1.23
1.85	1.29	1.28	1.15	1.18	1.18	1.21
3.45	1.37	1.34	1.22	1.28	1.24	1.28
S.E.	0.05	0.04	0.06	0.07	0.06	0.05
	Barley (n=18 to 30[c])					
0.55	1.23	1.45	1.26	1.35	1.33	1.33
0.95	1.22	1.40	1.28	1.29	1.34	1.30
1.35	1.27	1.41	1.32	1.35	1.37	1.34
1.85	1.27	1.39	1.33	1.39	1.37	1.35
3.45	1.26	1.35	1.30	1.30	1.33	1.31
S.E.	0.07	0.05	0.09	0.07	0.06	0.06

[a] The effective subsoil root zone = 15 to 185 cm (Forage); 15 to 85 cm (Barley).

[b] There were no significant differences between mean dry bulk density readings within suplots between treatments.

[c] Two tubes x 3 reps x depths (3 to 12 forage; 3 to 5 barley).

Table 10. Comparison of October soil dry bulk density between crops within subsoil thicknesses for the effective subsoil root zone[a] - subsoil depth experiment.

Crop	Year 1983	1984	1985	1986	1987	5 Year Mean
	Dry Bulk Density[b] (g/cc)					
	0.55m Subsoil Treatment (n=18)					
Forage	1.30a	1.32b	1.15a	1.25a	1.21a	1.25a
Barley	1.23a	1.45a	1.26a	1.35a	1.33a	1.33a
S.E.	0.03	0.02	0.11	0.11	0.08	0.06
	0.95m Subsoil Treatment (n=18 to 30)					
Forage	1.30a	1.24a	1.16a	1.21a	1.20a	1.22a
Barley	1.24a	1.40a	1.28a	1.29a	1.34a	1.30a
S.E.	0.08	0.05	0.12	0.07	0.05	0.06
	1.35m Subsoil Treatment (n=18 to 54)					
Forage	1.30a	1.26b	1.17b	1.20b	1.21b	1.23b
Barley	1.27a	1.41a	1.32a	1.35a	1.37a	1.34a
S.E.	0.03	0.08	0.03	0.04	0.06	0.02
	1.85m Subsoil Treatment (n=18 to 54)					
Forage	1.29a	1.28a	1.15a	1.18a	1.18a	1.21a
Barley	1.27a	1.39a	1.33a	1.39a	1.37a	1.35a
S.E.	0.02	0.12	0.01	0.02	0.01	0.02
	3.45m Subsoil Treatment (n=18 to 72)					
Forage	1.37a	1.34a	1.22a	1.28a	1.24a	1.28a
Barley	1.26a	1.35a	1.30a	1.30a	1.33a	1.31a
S.E.	0.13	0.06	0.07	0.05	0.04	0.05

[a] The effective subsoil root zone = 15 to 185 cm (Forage); 15 to 85 cm (Barley).

[b] Means down the same column (within subtables) followed by the same letter are not signficantly different at the 5% level (Duncan's multiple comparison of means).

Table 11. Comparison of October soil dry bulk density between years within crops for the effective subsoil root zone[a] - subsoil depth experiment.

	Subsoil Thickness					
Year	0.55m	0.95m	1.35m	1.85m	3.45m	Mean
	Dry Bulk Density[b] (g/cc)					
	Forage (n=18 to 72)					
1983	1.30ab	1.30a	1.30a	1.29a	1.37a	1.31a
1984	1.32a	1.24a	1.26ab	1.28a	1.34ab	1.29b
1985	1.15d	1.16a	1.17c	1.15a	1.22c	1.18d
1986	1.25bc	1.21a	1.20bc	1.18a	1.28bc	1.22c
1987	1.21cd	1.20a	1.21bc	1.18a	1.24c	1.21c
S.E.	0.03	0.02	0.03	0.02	0.03	0.01
	Barley (n=18 to 30)					
1983	1.23a	1.22c	1.27a	1.27a	1.26a	1.26d
1984	1.45a	1.40a	1.41a	1.39a	1.35a	1.40a
1985	1.26a	1.28bc	1.32a	1.33a	1.30a	1.30c
1986	1.35a	1.29abc	1.35a	1.39a	1.30a	1.34b
1987	1.33a	1.34ab	1.37a	1.37a	1.33a	1.35b
S.E.	0.07	0.05	0.03	0.02	0.03	0.02

[a] Effective subsoil root zone = 15 to 185 cm (Forage); 15 to 85 cm (Barley).

[b] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

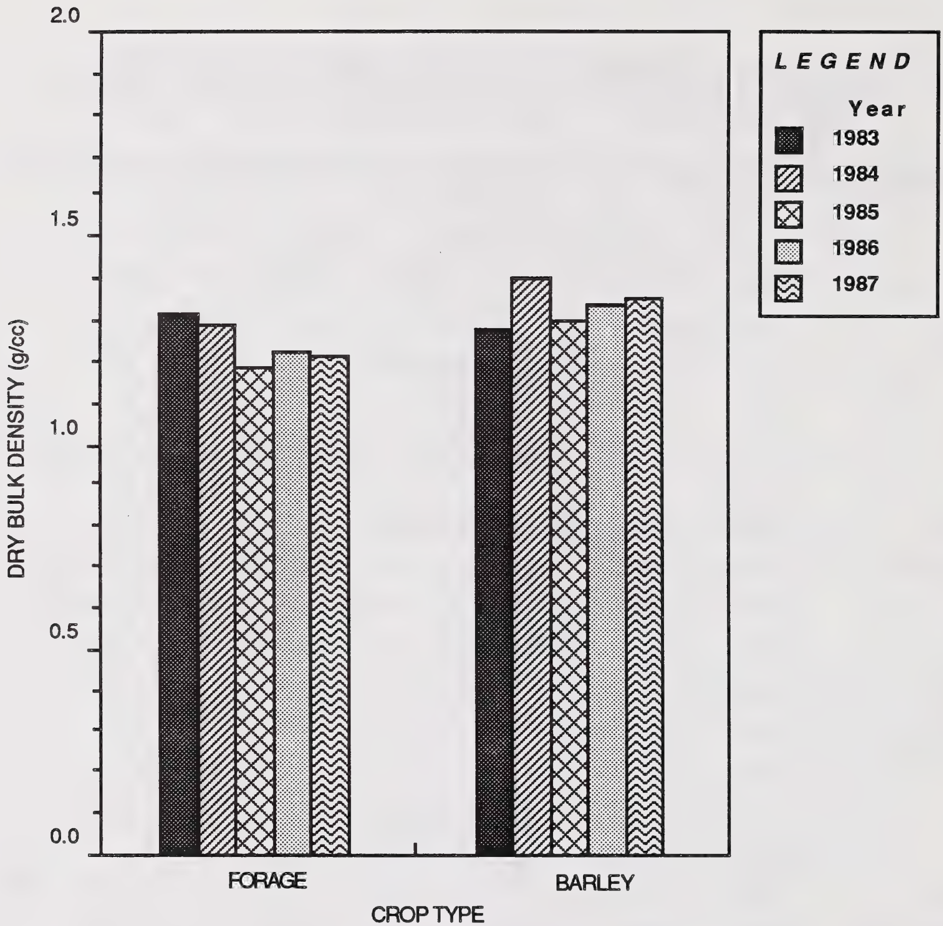


Figure 8. Comparison of soil dry bulk density (g/cc) between years within the forage and barley subplots for the effective subsoil root zone - subsoil depth experiment.

the 15 cm increment above the contact has been summarized in Tables 12, 13 and 14. There were no differences between subsoil thicknesses and no identifiable trends under forage or barley for any of the soil chemistry parameters. EC_e values remained very low (generally less than 1.0 mS/cm) across all treatments. Na and SAR values tended to be higher in the 0.95 m treatment under forage and the 1.35 m treatment under cereals. However, the differences between subsoil thicknesses were not significant.

3.2.5.2 Soil Chemistry Between Crops. A comparison of soil chemistry (EC_e, Na, SAR) parameters between crops within subsoil thicknesses for the 15 cm increment above the subsoil/minespoil contact has been summarized in Tables 15, 16 and 17. There were no differences between crops and no identifiable trends within subsoil thicknesses for any of the soil chemistry parameters. EC_e values remain very low, while Na and SAR values were variable and inconsistent.

3.2.5.3 Soil Chemistry Between Years. A comparison of soil chemistry (EC_e, Na, SAR) parameters between years for the 15 cm increment above the subsoil/minespoil contact has been summarized in Tables 18, 19 and 20 and Figures 9, 10 and 11. There were no differences between years or identifiable trends for EC_e values under either crop (Table 18). EC_e values remained low across all years.

There was an increase in SAR above the subsoil/minespoil contact from 1982 (plots constructed) to 1983 (first year of crop growth) for the 1.35 m treatment under barley and the 3.45 m treatment under forage. A similar trend in increasing Na and SAR values was apparent on many other treatments after the first year. However, Na and SAR values from 1984 to 1987 were variable and followed no consistent trend.

The SAR values measured on the 0.00 m treatment (topsoil overlying minespoil) over the five year monitoring period increased

Table 12. Comparison of soil electrical conductivity (EC_e) between subsoil thicknesses within crops for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

Subsoil Thickness (m)	Year 1982	1983	1984	1985	1986	1987	6 Year Mean
	Electrical Conductivity[a] (mS/cm)						
	Forage (n=6)						
0.55	0.4	0.5	0.5	0.7	0.6	0.4	0.5
0.95	1.0	0.5	0.7	0.9	0.7	0.8	0.8
1.35	0.5	0.7	0.7	0.9	0.6	0.9	0.7
1.85	0.5	0.5	0.8	0.5	0.7	0.6	0.6
3.45	0.4	0.7	0.5	0.7	0.6	0.8	0.6
S.E.	0.4	0.2	0.1	0.2	0.2	0.3	0.02
	Barley (n=6)						
0.55	0.5	0.5	0.5	0.7	0.6	0.7	0.6
0.95	0.5	0.8	0.6	1.2	0.6	0.7	0.7
1.35	0.6	0.7	0.7	0.8	0.8	1.0	0.8
1.85	0.6	0.7	0.6	0.7	0.5	0.7	0.6
3.45	0.5	1.1	0.6	0.5	1.1	0.9	0.8
S.E.	0.1	0.3	0.1	0.2	0.3	0.3	0.2

[a] There were no significant differences in EC between treatments within subplots.

Table 13. Comparison of Na between subsoil thicknesses within crops for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

Subsoil Thickness (m)	Year 1982	1983	1984	1985	1986	1987	6 Year Mean
	Soluble Sodium[a] (me/L)						
	Forage (n=6)						
0.55	0.9	3.1	3.0	5.2	4.5	2.2	3.2
0.95	6.3	3.0	3.7	6.0	5.6	5.2	4.9
1.35	1.2	4.3	4.9	5.8	3.8	6.7	4.5
1.85	1.6	2.2	4.4	3.1	3.8	3.0	3.0
3.45	1.0	3.8	1.9	5.1	3.0	5.3	3.4
S.E.	3.5	2.0	1.5	1.8	1.5	2.5	1.5
	Barley (n=6)						
0.55	1.5	2.4	2.1	3.8	4.1	4.0	3.0
0.95	1.5	4.9	3.0	8.4	4.4	4.8	4.5
1.35	1.6	4.5	5.3	5.8	6.5	8.2	5.3
1.85	2.0	3.9	3.1	4.0	1.7	4.4	3.2
3.45	1.0	7.5	2.8	2.2	8.3	6.1	4.6
S.E.	1.2	2.7	1.1	2.7	2.5	2.1	1.3

[a] There were no significant differences in soluble sodium levels between treatments within subplots.

Table 14. Comparison of SAR between subsoil thicknesses within crops for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

Subsoil Thickness (m)	Year 1982	1983	1984	1985	1986	1987	6 Year Mean
				SAR			
				Forage[a] (n=6)			
0.55	0.6	2.8	2.8	6.0	4.5	2.0	3.2
0.95	9.1	2.5	3.0	5.2	7.5	4.3	5.3
1.35	0.9	6.2	6.2	4.5	3.8	6.2	4.7
1.85	1.3	1.7	3.4	2.8	3.1	2.8	2.5
3.45	0.7	2.9	1.5	4.8	2.5	4.8	2.9
S.E.	5.4	3.0	2.0	2.1	2.0	1.6	1.3
				Barley[a] (n=6)			
0.55	1.3	1.9	1.7	3.5	3.9	3.6	2.7
0.95	1.1	4.0	2.3	6.8	3.8	4.0	3.7
1.35	1.2	3.8	5.2	5.1	9.6	7.5	5.4
1.85	1.6	3.2	2.6	4.0	1.3	3.8	2.8
3.45	0.7	6.0	2.1	1.9	12.3	4.8	4.6
S.E.	1.0	2.2	1.1	2.6	4.7	1.4	2.3

[a] There were no significant differences in SAR values between treatments within subplots.

Table 15. Comparison of soil EC_e between crops within subsoil thicknesses for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

Crop	Year 1982	1983	1984	1985	1986	1987	6 Year Mean
	Electrical Conductivity[a] (mS/cm)						
	0.55m Subsoil Treatment (n=6)						
Forage	0.4	0.5	0.5	0.7	0.6	0.4	0.5
Barley	0.5	0.5	0.5	0.7	0.6	0.7	0.6
S.E.	0.1	0.1	0.2	0.2	0.1	0.2	0.1
	0.95m Subsoil Treatment (n=6)						
Forage	1.0	0.5	0.7	0.9	0.7	0.8	0.8
Barley	0.5	0.8	0.6	1.2	0.6	0.7	0.7
S.E.	0.5	0.1	0.2	0.5	0.1	0.3	0.2
	1.35m Subsoil Treatment (n=6)						
Forage	0.5	0.7	0.7	0.9	0.6	0.9	0.7
Barley	0.6	0.7	0.7	0.8	0.8	1.0	0.8
S.E.	0.1	0.1	0.1	0.2	0.1	0.2	0.1
	1.85m Subsoil Treatment (n=6)						
Forage	0.5	0.5	0.8	0.5	0.7	0.6	0.6
Barley	0.6	0.7	0.6	0.7	0.5	0.7	0.6
S.E.	0.2	0.1	0.1	0.2	0.1	0.1	0.1
	3.45m Subsoil Treatment (n=6)						
Forage	0.4	0.7	0.5	0.7	0.6	0.8	0.6
Barley	0.5	1.1	0.6	0.5	1.1	0.9	0.8
S.E.	0.1	0.3	0.1	0.1	0.6	0.1	0.1

[a] There were no significant differences in the EC values between subplots within treatments.

Table 16. Comparison of Na between crops within subsoil thicknesses for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

Crop	Year 1982	1983	1984	1985	1986	1987	6 Year Mean
	Soluble Sodium[a] (me/L)						
	0.55m Subsoil Treatment (n=6)						
Forage	0.9	3.1	3.0	5.2	4.5	2.2	3.2
Barley	1.5	2.4	2.1	3.8	4.1	4.0	3.0
S.E.	0.9	1.1	2.0	2.0	1.4	0.8	0.8
	0.95m Subsoil Treatment (n=6)						
Forage	6.3	3.0	3.7	6.0	5.6	5.2	4.9
Barley	1.5	4.9	3.0	8.4	4.4	4.8	4.5
S.E.	6.1	0.8	1.5	5.0	1.2	2.3	2.0
	1.35m Subsoil Treatment (n=6)						
Forage	1.2	4.3	4.9	5.8	3.8	6.7	4.5
Barley	1.6	4.5	5.3	5.8	6.5	8.2	5.3
S.E.	0.4	1.6	0.6	1.4	1.1	1.3	0.4
	1.85m Subsoil Treatment (n=6)						
Forage	1.6	2.2	4.4	3.1	3.8	3.0	3.0
Barley	2.0	3.9	3.1	4.0	1.7	4.4	3.2
S.E.	1.3	0.3	0.6	1.8	0.5	0.2	0.5
	3.45m Subsoil Treatment (n=6)						
Forage	1.0	3.8	1.9	5.1	3.0	5.3	3.4
Barley	1.0	7.5	2.8	2.2	8.3	6.1	4.6
S.E.	0.2	3.2	0.4	0.7	2.8	1.1	1.1

[a] There were no significant differences in Na values between subplots within treatments.

Table 17. Comparison of SAR between crops within subsoil thicknesses for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

Crop	Year 1982	1983	1984	1985	1986	1987	6 Year Mean
				SAR[a]			
				0.55m Subsoil Treatment (n=6)			
Forage	0.6	2.8	2.8	6.0	4.5	2.0	3.2
Barley	1.3	1.9	1.7	3.5	3.9	3.6	2.7
S.E.	0.9	1.1	1.9	3.2	1.1	0.5	0.8
				0.95m Subsoil Treatment (n=6)			
Forage	9.1	2.5	3.0	5.2	7.5	4.3	5.3
Barley	1.1	4.0	2.3	6.8	3.8	4.0	3.7
S.E.	9.1	0.6	1.3	4.5	3.6	1.7	2.1
				1.35m Subsoil Treatment (n=6)			
Forage	0.9	6.2	6.2	4.5	3.8	6.2	4.7
Barley	1.2	3.8	5.2	5.1	9.6	7.5	5.4
S.E.	0.3	3.9	0.8	0.9	3.7	0.7	0.2
				1.85m Subsoil Treatment (n=6)			
Forage	1.3	1.7	3.4	2.8	3.1	2.8	2.5
Barley	1.6	3.2	2.6	4.0	1.3	3.8	2.8
S.E.	1.0	0.2	0.4	1.9	0.4	0.5	0.3
				3.45m Subsoil Treatment (n=6)			
Forage	0.7	2.9	1.5	4.8	2.5	4.8	2.9
Barley	0.7	6.0	2.1	1.9	12.3	4.8	4.6
S.E.	0.2	2.8	0.2	1.1	6.0	1.2	1.3

[a] There were no significant differences in SAR values between subplots within treatments.

Table 18. Comparison of soil EC_e between years within crops for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

	Subsoil Thickness					
Year	0.55m	0.95m	1.35m	1.85m	3.45m	Mean
	Electrical Conductivity[a] (mS/cm)					
	Forage (n=6)					
1982	0.4	1.0	0.5	0.5	0.4	0.6
1983	0.5	0.5	0.7	0.5	0.7	0.6
1984	0.5	0.7	0.7	0.8	0.5	0.6
1985	0.7	0.9	0.9	0.5	0.7	0.7
1986	0.6	0.7	0.6	0.7	0.6	0.6
1987	0.4	0.8	0.9	0.6	0.8	0.7
S.E.	0.1	0.3	0.2	0.2	0.1	0.1
	Barley (n=6)					
1982	0.5	0.5	0.6	0.6	0.5	0.5
1983	0.5	0.8	0.7	0.7	1.1	0.8
1984	0.5	0.6	0.7	0.6	0.6	0.6
1985	0.7	1.2	0.8	0.7	0.5	0.8
1986	0.6	0.6	0.8	0.5	1.1	0.7
1987	0.7	0.7	1.0	0.7	0.9	0.8
S.E.	0.1	0.2	0.1	0.2	0.3	0.1

[a] There were no significant differences in EC_e values between years within subplots.

Table 19. Comparison of Na between years within crops for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

Year	Subsoil Thickness 0.55m	0.95m	1.35m	1.85m	3.45m	Mean
	Soluble Sodium[a] (me/L)					
	Forage (n=6)					
1982	0.9a	6.3a	1.2a	1.6a	1.0a	2.2a
1983	3.1a	3.0a	4.3a	2.2a	3.8a	3.3a
1984	3.0a	3.7a	4.9a	4.4a	1.9a	3.6a
1985	5.2a	6.0a	5.8a	3.1a	5.1a	5.0a
1986	4.5a	5.6a	3.8a	3.8a	3.0a	4.2a
1987	2.2a	5.2a	6.7a	3.0a	5.3a	4.5a
S.E.	1.6	3.2	1.9	1.3	1.0	1.0
	Barley (n=6)					
1982	1.5a	1.5a	1.6c	2.0a	1.0a	1.5c
1983	2.4a	4.9a	4.5bc	3.9a	7.5a	4.9a
1984	2.1a	3.0a	5.3ab	3.1a	2.8a	3.2b
1985	3.8a	8.4a	5.8ab	4.0a	2.2a	4.8a
1986	4.1a	4.4a	6.5ab	1.7a	8.3a	5.0a
1987	4.0a	4.8a	8.2a	4.4a	6.1a	5.5a
S.E.	1.1	2.1	1.4	1.8	2.6	0.7

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

Table 20. Comparison of SAR between years within crops for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

	Subsoil Thickness					
Year	0.55m	0.95m	1.35m	1.85m	3.45m	Mean
			SAR			
			Forage[a] (n=6)			
1982	0.6a	9.1a	0.9a	1.3a	0.7c	2.6a
1983	2.8a	2.5a	6.2a	1.7a	2.9ab	3.2a
1984	2.8a	3.0a	6.2a	3.4a	1.5bc	3.4a
1985	6.0a	5.2a	4.5a	2.8a	4.8a	4.7a
1986	4.5a	7.5a	3.8a	3.1a	2.5bc	4.3a
1987	2.0a	4.3a	6.2a	2.8a	4.8a	4.0a
S.E.	2.0	5.4	3.0	1.0	0.8	1.3
			Barley[a] (n=6)			
1982	1.3a	1.1a	1.2c	1.6a	0.7a	1.2c
1983	1.9a	4.0a	3.8bc	3.2a	6.0a	4.0b
1984	1.7a	2.3a	5.2abc	2.6a	2.1a	2.7bc
1985	3.5a	6.8a	5.1abc	4.0a	1.9a	4.3ab
1986	3.9a	3.8a	9.6a	1.3a	12.3a	6.2a
1987	3.6a	4.0a	7.5ab	3.8a	4.8a	4.8ab
S.E.	1.1	1.9	2.1	1.7	3.8	0.9

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

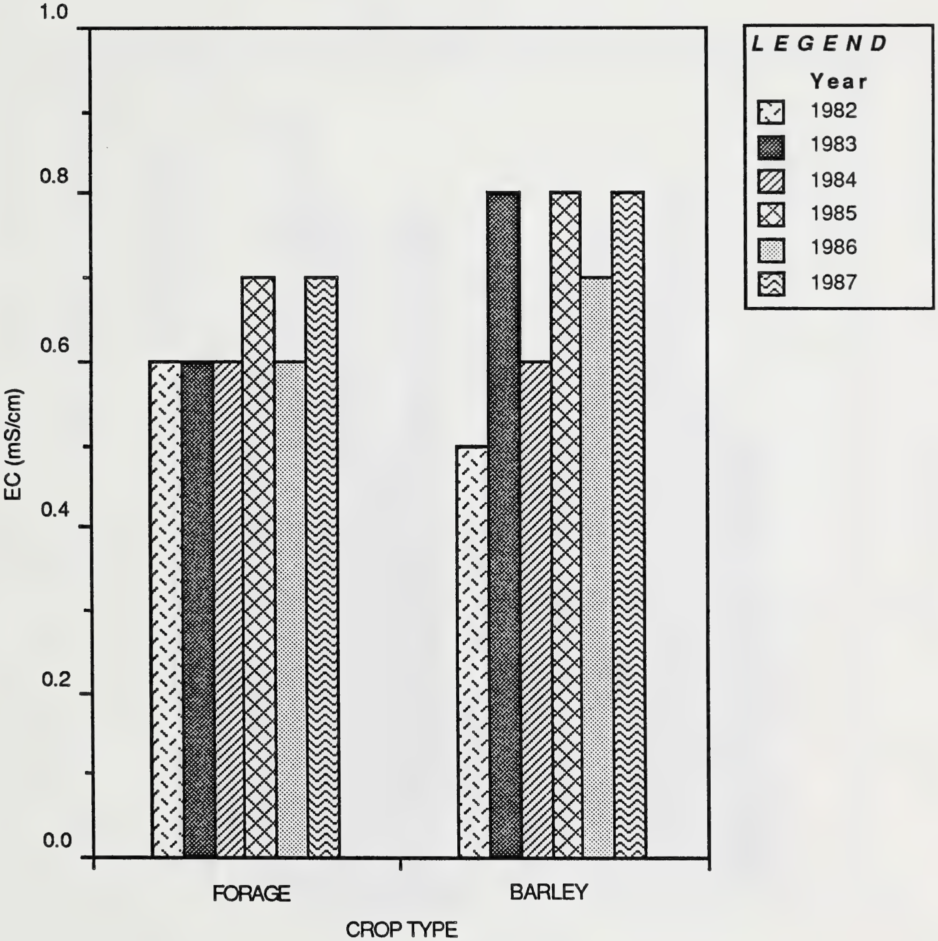


Figure 9. Comparison of mean soil EC (mS/cm) between years within the forage and barley subplots for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

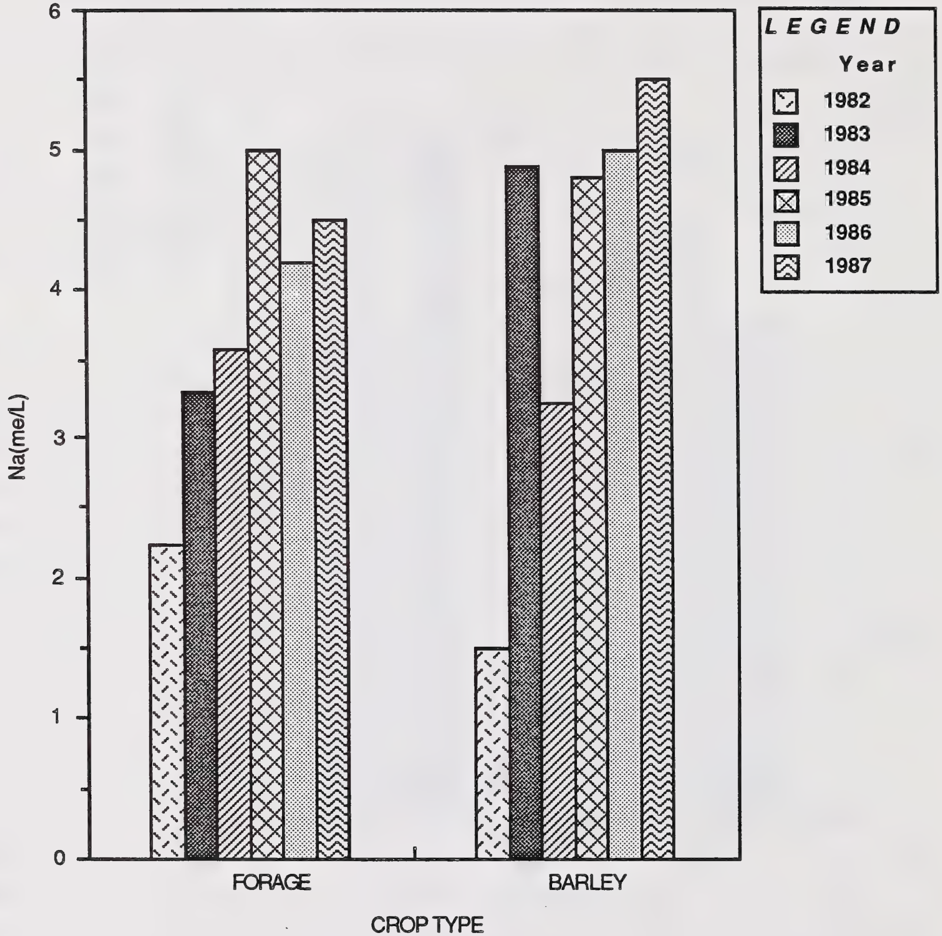


Figure 10. Comparison of Na (me/L) between years within the forage and barley subplots for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

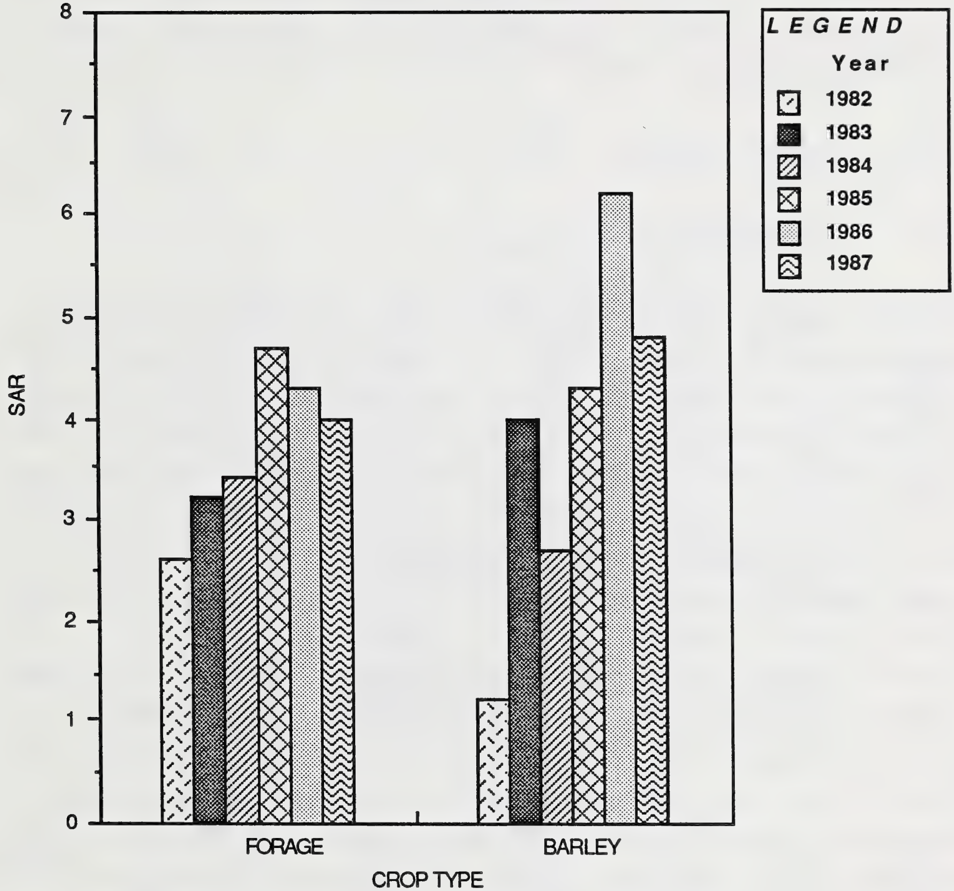


Figure 11. Comparison of SAR between years within the forage and barley subplots for the 15 cm increment immediately above the subsoil/minespoil contact - subsoil depth experiment.

from about 0.3 initially to 4.3 in the forage plots and to 7.2 in the cereal plots (Highvale Soil Reconstruction Reclamation Research Program Interim Report, 1987).

3.3 SLOPE EXPERIMENT

3.3.1 Forage Yield

3.3.1.1 Forage Yield Between Slope Types. A comparison of forage yields between slope types within slope positions has been summarized in Table 21 and Figure 12. Yields were higher (5 year means) on the 5° North treatment than on the 5° and 10° South treatments at the lower slope position. Yields at the mid slope position were higher on the 5° North and South treatments than on the 10° South treatment. The 5° North treatment was more productive than all other treatments at the upper slope position.

3.3.1.2 Forage Yield Between Slope Positions. The effect of slope position on forage yield within slope types has been summarized in Table 22. Forage yields (5 year mean) on the 5° South treatment were lower on the lower slope position than mid and upper slope positions. There was a similar trend toward lower production at the lower slope position for the remaining slope types, especially during the first two to three years of production. These trends were significant for all slope types until the third year of production in 1985.

3.3.1.3 Forage Yield Between Years. Forage yields were lowest during the first year and increased until the fourth year of production in 1986 for all slope types and slope positions (Table 23). Yields decreased slightly across most slope types and slope positions in 1987. Productivity generally increased from the first to the fourth year, regardless of seasonal moisture availability in the Highvale area.

Table 21. Comparison of annual forage[a] yields between slope types within slope positions - slope experiment.

Slope Type (Aspect x Slope)		1983	1984	1985	1986	1987	5 Year Mean
		Forage Yields[b] (g/m^2)					
		Lower Slope (n=6)					
North	5°	68a	396a	529a	691a	577a	452a
	10°	66a	362ab	410a	634ab	550a	404ab
South	5°	98a	328ab	327a	512c	530a	345b
	10°	70a	299b	363a	544bc	460a	361b
S.E.		27	30	81	37	35	24
		Mid Slope (n=6)					
North	5°	144ab	571a	648a	696a	540a	520a
	10°	99b	498ab	542ab	629ab	476a	449ab
South	5°	183a	417b	564a	595ab	637a	479a
	10°	150ab	356b	439b	493b	528a	393b
S.E.		22	60	42	60	74	29
		Upper Slope (n=6)					
North	5°	169a	612a	739a	675a	579a	555a
	10°	149a	500b	570ab	626ab	466ab	462b
South	5°	186a	399c	492b	555ab	509ab	428bc
	10°	193a	311d	369b	511b	400b	357c
S.E.		26	34	81	48	47	32

[a] Forage = oven dry biomass (total yield).

[b] Means down the same column (within subtables) followed by the same letter are not signficantly different at the 5% level (Duncan's multiple comparison of means).

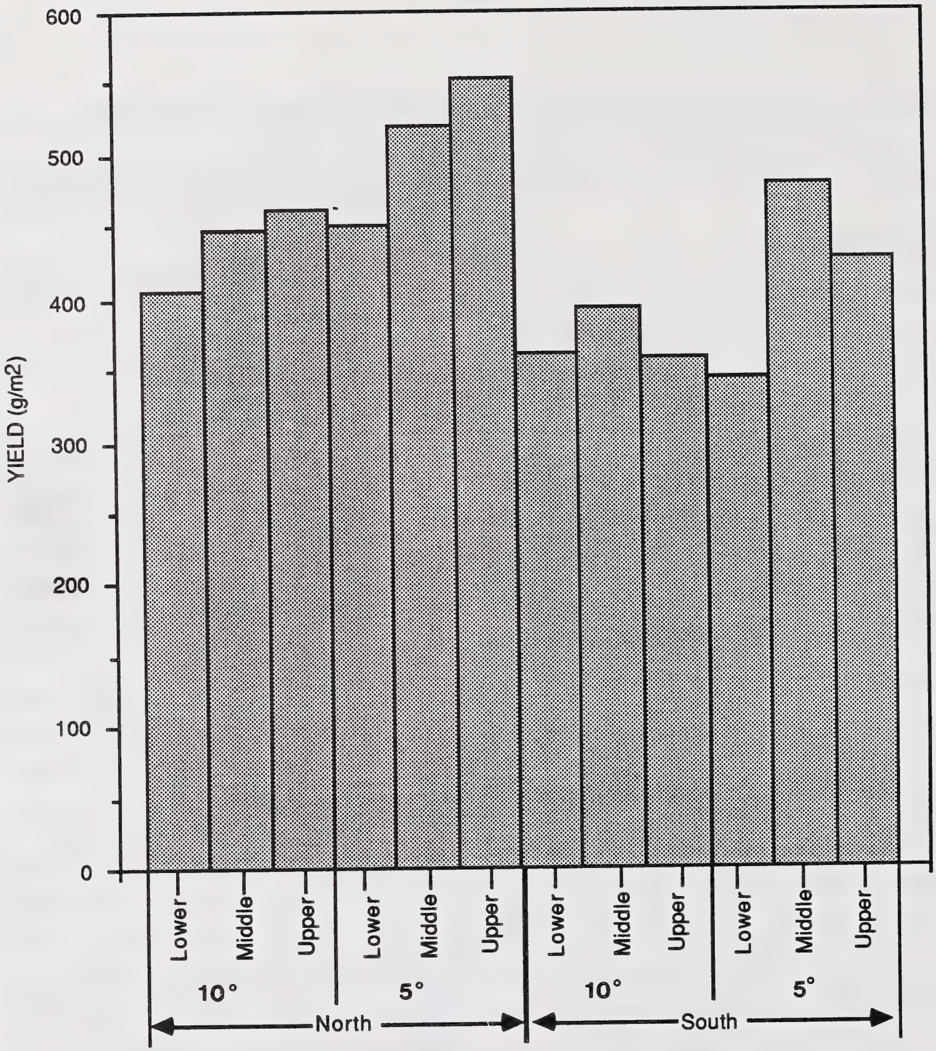


Figure 12. Comparison of 5 year mean forage yields (g/m ^{2}) between treatment x slope position interactions - slope experiment.

Table 22. Comparison of annual forage[a] yields between slope positions within slope types - slope experiment.

Slope Position	Year 1983	1984	1985	1986	1987	5 Year Mean
			Forage Yields[b] (g/m^2)			
			North 5° Treatment (n=6)			
Lower	68b	397b	529a	691a	577a	452a
Middle	144a	571a	648a	696a	540a	520a
Upper	169a	612a	739a	675a	579a	555a
S.E.	17	39	122	73	37	43
			North 10° Treatment (n=6)			
Lower	66b	362b	410b	634a	550a	404a
Middle	99ab	498a	542a	629a	476a	449a
Upper	149a	500a	570a	626a	466a	462a
S.E.	22	38	36	55	52	32
			South 5° Treatment (n=6)			
Lower	98a	328b	327b	512a	460b	345b
Middle	183a	417a	564a	595a	637a	479a
Upper	186a	399a	492a	555a	509ab	428a
S.E.	33	22	40	39	55	25
			South 10° Treatment (n=6)			
Lower	70b	299b	363a	544a	530a	361a
Middle	150ab	356a	439a	493a	528a	393a
Upper	193a	311b	369a	510a	400b	357a
S.E.	30	13	73	25	42	18

a Forage = oven dry biomass.

b Means down the same column (within subtables) followed by the same letter are significantly different at the 5% level (Duncan's multiple comparison of means).

Table 23. Comparison of forage[a] yields between years within slope types and slope positions - slope experiment.

	Forage Yields[b] (g/m^2)							
	Slope Type (n=18[c])				Slope Position (n=24[d])			Mean
Year	North 5°	North 10°	South 5°	South 10°	Lower	Middle	Upper	
1983	127c	105c	156d	138d	76d	144c	174d	131d
1984	527b	453b	381c	322c	346c	461b	455c	421c
1985	639ab	507b	461bc	391bc	407c	548ab	542ab	499b
1986	687a	630a	554a	516a	595a	603a	592a	597a
1987	565b	497b	535ab	486ab	529b	545ab	488bc	521b
S.E.	47	27	35	47	28	37	35	31

[a] Forage = oven dry biomass.

[b] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

[c] 2 samples x 3 reps x 3 slope positions.

[d] 2 samples x 3 reps x 4 slope types.

Table 24. Comparison of slope experiment forage[a] yields - slope type x slope position interactions - slope experiment.

Slope Type (Aspect x Slope) x Position		Year 1983	1984	1985	1986	1987	5 Year Mean
		Forage Yields (g/m^2) n=6					
North 10°	Lower	66	36	410	634	550	404[b]
	Middle	99	498	542	629	476	449
	Upper	149	500	569	626	466	462
5°	Lower	68	397	529	691	577	452
	Middle	144	571	647	695	540	520
	Upper	169	612	738	676	579	555
South 10°	Lower	70	299	363	543	530	361
	Middle	150	356	439	493	528	393
	Upper	193	311	369	511	399	356
5°	Lower	98	327	326	512	460	345
	Middle	183	417	563	595	637	479
	Upper	186	399	492	554	509	428
Mean		131	421	499	597	521	434
S.E.		21	62	79	40	93	44

[a] Forage = oven dry biomass (total yield).

[b] There were no significant differences in forage yields between slope type x slope position interactions for the 5 year mean.

3.3.1.4 Forage Yield - Slope Type by Slope Position Interaction. There was no significant difference in yield between slope type and slope position interactions in 1983, 1985, 1986 and over the 5 year study period (Table 24). Although significant differences between treatments were indicated by statistical analysis for 1984 and 1987, these differences were not assigned a letter rating due to a limitation of the Duncan's multiple range test to assess interaction effects. The general trend in yield over 5 years shows that the 5° North upper slope position was most productive and the 5° South lower slope position was least productive over the five year study period.

3.3.2 Soil Moisture

3.3.2.1 Soil Moisture Between Slope Types. The effect of slope type on soil moisture within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact has been summarized in Table 25. The influence of slope type on soil moisture was not significant in the lower and mid slope positions over a 5 year period. However, moisture content at the upper slope position for the 15 cm increment above the subsoil/minespoil contact was significantly lower in the 10° South treatment than other treatments. At the mid and lower slope positions, there was a trend toward lower soil moisture above the contact in the 5° South treatment.

3.3.2.2 Soil Moisture Between Slope Positions. The results shown in Table 26 indicate that the upper slope position in the 10° South treatment had lower soil moisture levels above the subsoil/minespoil contact than the mid and lower slope positions over the 5 year study period. There was a general trend toward higher soil moisture levels above the subsoil/minespoil contact at the lower slope position within each slope type. The trend was not significant, except for the lower slope 10° North treatment in 1987.

Table 25. Comparison of average growing season soil moisture between slope types within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Slope Type (Aspect x Slope)		Year 1983	1984	1985	1986	1987	5 Year Mean
				Soil Moisture[a] (%)			
				Lower Slope (n=21[b])			
North	5°	33.0a	29.8a	32.8a	31.6a	29.3a	31.2a
	10°	33.1a	30.8a	33.9a	30.4a	29.2a	31.4a
South	5°	30.7b	28.2a	29.3a	28.6a	26.2a	28.6a
	10°	32.8a	30.6a	33.4a	30.2a	28.4a	31.0a
S.E.		0.7	1.7	2.4	1.4	2.0	1.5
				Mid Slope (n=21)			
North	5°	31.8a	27.3a	27.7a	28.8a	25.2a	27.7a
	10°	32.1a	28.8a	30.8a	26.6a	25.0a	27.7a
South	5°	30.5a	24.6a	25.6a	25.6a	23.2a	25.9a
	10°	31.7a	28.9a	28.9a	27.9a	26.3a	28.6a
S.E.		1.5	1.6	3.0	1.9	2.2	1.6
				Upper Slope (n=21)			
North	5°	31.5a	27.7a	28.2a	28.7a	26.7a	28.4a
	10°	31.3a	27.2a	26.1a	27.3ab	24.8ab	27.4a
South	5°	32.0a	27.3a	28.8a	28.5a	28.1a	29.0a
	10°	29.0b	25.1a	25.6a	24.9b	22.9b	25.2b
S.E.		0.5	0.5	1.5	1.1	1.4	0.7

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

[b] One tube x 3 reps x 7 readings.

Table 26. Comparison of average growing season soil moisture between slope positions within slope types for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Slope Position	1983	1984	1985	1986	1987	5 Year Mean
			Soil Moisture[a] (%)			
			North 5° Treatment (n=21)			
Lower	33.0a	29.8a	32.8a	31.6a	29.3a	31.2a
Middle	31.8a	27.3a	27.7a	28.8a	25.2a	27.7a
Upper	31.5a	27.7a	28.2a	28.7a	26.7a	28.4a
S.E.	0.9	1.2	2.0	0.6	1.9	1.0
			North 10° Treatment (n=21)			
Lower	33.1a	30.8a	33.9a	30.4a	29.2a	31.4a
Middle	32.1ab	28.8a	30.8a	26.6a	25.0b	27.7a
Upper	31.3b	27.2a	26.1a	27.3a	24.8b	27.4a
S.E.	0.4	1.5	3.1	1.8	1.3	1.3
			South 5° Treatment (n=21)			
Lower	30.7a	28.2a	29.3a	28.6a	26.2a	28.6a
Middle	30.5a	24.6a	25.6a	25.6a	23.2a	25.9a
Upper	32.0a	27.3a	28.8a	28.5a	28.1a	29.0a
S.E.	1.0	1.5	2.2	1.4	1.8	1.4
			South 10° Treatment (n=21)			
Lower	32.8a	30.6a	33.4a	30.2a	28.4a	31.0a
Middle	31.7a	28.9a	28.9ab	27.9ab	26.3ab	28.6a
Upper	29.0a	25.1b	25.6b	24.9b	22.9b	25.2b
S.E.	1.0	0.8	1.9	1.4	1.4	1.2

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

3.3.2.3 Soil Moisture Between Years. A comparison of soil moisture content between years for the 15 cm increment above the subsoil/minespoil contact has been summarized in Table 27 and Figure 13. The soil moisture content decreased significantly over time under the forage crop at all three slope positions over the 5 year study period. The first distinct decrease in soil moisture was observed between 1983 (crop establishment year) and 1984 (first full year of growth). A trend toward decreasing soil moisture over time was apparent within all slope types. This trend was consistent with soil moisture decreases noted under forage for the 0.55 m depth experiment (similar subsoil thickness on horizontal topography). However, the soil moisture results of the slope experiment would likely be considerably different under a continuous cereal cropping practice.

3.3.3 Soil Bulk Density

3.3.3.1 Soil Bulk Density Between Slope Types. A comparison of October soil dry bulk density values between slope types for the subsoil root zone has been summarized in Table 28. There were no differences in bulk density between slope types and no identifiable trends in any year.

3.3.3.2 Soil Bulk Density Between Slope Positions. A comparison of October soil dry bulk density between slope positions has been summarized in Table 29. The bulk density of the upper slope position in the 10° South treatment was less than that of the lower and mid slope positions over the 5 year duration of the study. There was a general trend toward lower bulk density at the upper slope position for the 5° and 10° North treatments.

3.3.3.3 Soil Bulk Density Between Years. Bulk density has decreased over time in the lower and mid slope positions across all slope types, but has not changed significantly in the upper slope position

Table 27. Changes in average growing season soil moisture between years within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Year	Slope Type (Aspect x Slope)				Mean
	North 5°	North 10°	South 5°	South 10°	
			Soil Moisture[a] (%)		
			Lower Slope (n=21)		
1983	33.0a	33.1a	30.7a	32.8a	32.4a
1984	29.8a	30.8a	28.2a	30.6a	29.8b
1985	32.8a	33.9a	29.3a	33.3a	32.3a
1986	31.6a	30.4a	28.6a	30.2a	30.2b
1987	29.3a	29.2a	26.2a	28.4a	28.3c
S.E.	0.8	1.2	0.7	0.9	0.5
			Mid Slope (n=21)		
1983	31.8a	32.1a	30.5a	31.7a	31.4a
1984	27.3b	28.8a	24.6a	28.9a	27.4b
1985	27.7b	30.8a	25.6a	28.9a	27.8b
1986	28.8ab	26.6a	25.6a	27.9a	27.2b
1987	25.2b	25.0a	23.2a	26.3a	24.9c
S.E.	1.3	0.7	0.9	0.7	0.6
			Upper Slope (n=21)		
1983	31.5a	31.5a	32.0a	29.0a	31.1a
1984	27.7a	27.2a	27.3b	25.1a	26.8b
1985	28.2a	26.1a	28.8b	25.6a	27.1b
1986	28.7a	27.3a	28.5b	24.9a	27.3b
1987	26.7a	24.8a	28.1b	22.9a	25.6c
S.E.	1.2	0.7	0.7	0.4	0.4

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

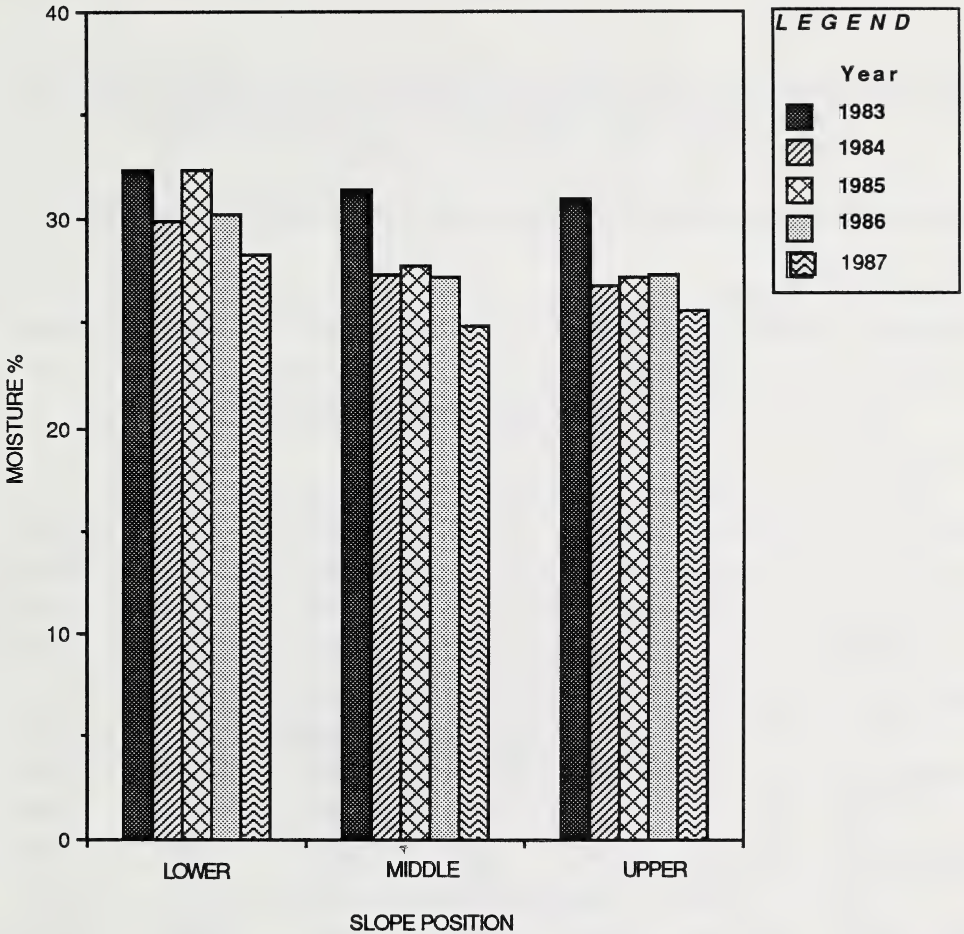


Figure 13. Comparison of average seasonal soil moisture (%) between years within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Table 28. Comparison of October soil dry bulk density between slope types within slope positions for the effective subsoil root zone - slope experiment.

Slope Type (Aspect x Slope)		Year 1983	1984	1985	1986	1987	5 Year Mean
		Bulk Density[a] (g/cc)					
		Lower Slope (n=18[b])					
North	5°	1.43	1.45	1.37	1.39	1.31	1.39
	10°	1.41	1.53	1.43	1.43	1.31	1.41
South	5°	1.29	1.41	1.33	1.32	1.27	1.32
	10°	1.31	1.46	1.40	1.36	1.29	1.37
S.E.		0.05	0.05	0.05	0.05	0.04	0.04
		Mid Slope (n=18)					
North	5°	1.40	1.44	1.34	1.39	1.33	1.38
	10°	1.37	1.39	1.28	1.30	1.17	1.30
South	5°	1.29	1.42	1.25	1.28	1.26	1.30
	10°	1.38	1.43	1.35	1.33	1.32	1.36
S.E.		0.07	0.08	0.09	0.11	0.10	0.08
		Upper Slope (n=18)					
North	5°	1.33	1.40	1.27	1.38	1.36	1.35
	10°	1.28	1.35	1.21	1.33	1.19	1.27
South	5°	1.36	1.44	1.36	1.32	1.35	1.36
	10°	1.22	1.35	1.26	1.25	1.22	1.25
S.E.		0.06	0.02	0.05	0.03	0.08	0.04

[a] There were no significant differences between mean dry bulk density values between treatments within subplots.

[b] One tube x 3 reps x 6 depths.

Table 29. Comparison of October soil dry bulk density between slope positions within slope types for the effective subsoil root zone - slope experiment.

Slope Position	Year 1983	1984	1985	1986	1987	5 Year Mean
	Bulk Density[a] (g/cc)					
	North 5° Treatment (n=18)					
Lower	1.43a	1.45a	1.37a	1.39a	1.31a	1.39a
Middle	1.40a	1.44a	1.34a	1.39a	1.33a	1.38a
Upper	1.33a	1.40a	1.27a	1.38a	1.36a	1.35a
S.E.	0.07	0.06	0.12	0.10	0.10	0.09
	North 10° Treatment (n=18)					
Lower	1.41a	1.53a	1.43a	1.43a	1.31a	1.41a
Middle	1.37a	1.39a	1.28ab	1.30a	1.17a	1.30a
Upper	1.28a	1.35a	1.21b	1.33a	1.19a	1.27a
S.E.	0.07	0.08	0.06	0.04	0.06	0.05
	South 5° Treatment (n=18)					
Lower	1.29a	1.41a	1.33a	1.32a	1.27a	1.32a
Middle	1.29a	1.42a	1.25a	1.28a	1.26a	1.30a
Upper	1.36a	1.44a	1.36a	1.32a	1.35a	1.36a
S.E.	0.03	0.05	0.05	0.06	0.05	0.04
	South 10° Treatment (n=18)					
Lower	1.31a	1.46a	1.40a	1.36a	1.29a	1.37a
Middle	1.38a	1.43a	1.35a	1.33a	1.32a	1.36a
Upper	1.22a	1.35a	1.27a	1.25a	1.22a	1.25b
S.E.	0.07	0.05	0.05	0.05	0.07	0.03

[a] Means down the same column (within subtables) followed by the same letter are not signficantly different at the 5% level (Duncan's multiple comparison of means).

(Table 30 and Figure 14). Decreasing soil dry bulk density values over time were consistent with decreasing values under forage in the depth experiment 0.55 m treatment. The lack of change in the upper slope position probably reflects a lower initial soil bulk density.

3.3.4 Soil Chemistry

3.3.4.1 Soil Chemistry Between Slope Types. Comparisons of soil chemical parameters (EC_e, Na and SAR) between slope types within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact have been summarized in Tables 31, 32 and 33. Table 31 shows minor fluctuations in EC_e between slope types within some years. However, there were no EC_e mean values reported in excess of 1 mS/cm for any slope type. Table 32 shows few differences in Na between slope types, although Na levels were higher in the 5° South treatment at the lower slope position in 1986. Table 33 shows no significant differences in SAR levels between slope types over six years of monitoring.

3.3.4.2 Soil Chemistry Between Slope Positions. Comparisons of EC_e, soluble Na and SAR between slope positions within slope types for the 15 cm increment immediately above the subsoil/minespoil interface have been summarized in Tables 34, 35 and 36. There was a significant difference in EC_e between lower, and mid and upper slope positions in the 5° South treatment in 1986 (Table 34). However, the maximum mean EC_e value was 1.0 mS/cm. Table 35 shows soluble Na levels were significantly lower in the mid slope position compared to lower and upper slope positions on the 10° North treatment in 1986. SAR values between slope positions within slope types show the same trends as soluble Na (Table 36).

3.3.4.3 Soil Chemistry Between Years. A comparison of soil EC_e between years within slope positions for the 15 cm increment above the

Table 30. Comparison of October soil dry bulk density between years within slope positions for the effective subsoil root zone - slope experiment.

Year	Slope Type (Aspect x Slope) North 5°	North 10°	South 5°	South 10°	Mean
	Bulk Density[a] (g/cc)				
	Lower Slope (n=18)				
1983	1.43a	1.41a	1.29b	1.31a	1.36b
1984	1.45a	1.53a	1.41a	1.46a	1.46a
1985	1.37a	1.43a	1.33b	1.40a	1.38b
1986	1.39a	1.43a	1.32b	1.36a	1.38b
1987	1.31a	1.31a	1.27b	1.29a	1.30c
S.E.	0.04	0.02	0.03	0.04	0.02
	Mid Slope (n=18)				
1983	1.40a	1.37ab	1.29a	1.38a	1.36b
1984	1.44a	1.39a	1.42a	1.43a	1.42a
1985	1.34a	1.28c	1.25a	1.35a	1.30cd
1986	1.39a	1.30bc	1.28a	1.33a	1.32bc
1987	1.33a	1.17d	1.26a	1.32a	1.27d
S.E.	0.02	0.03	0.03	0.04	0.02
	Upper Slope (n=18)				
1983	1.33a	1.28a	1.36a	1.22a	1.30b
1984	1.40a	1.35a	1.44a	1.35a	1.38a
1985	1.27a	1.21a	1.36a	1.37a	1.27b
1986	1.38a	1.33a	1.32a	1.25a	1.32ab
1987	1.36a	1.19a	1.35a	1.22a	1.29b
S.E.	0.05	0.04	0.03	0.07	0.03

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

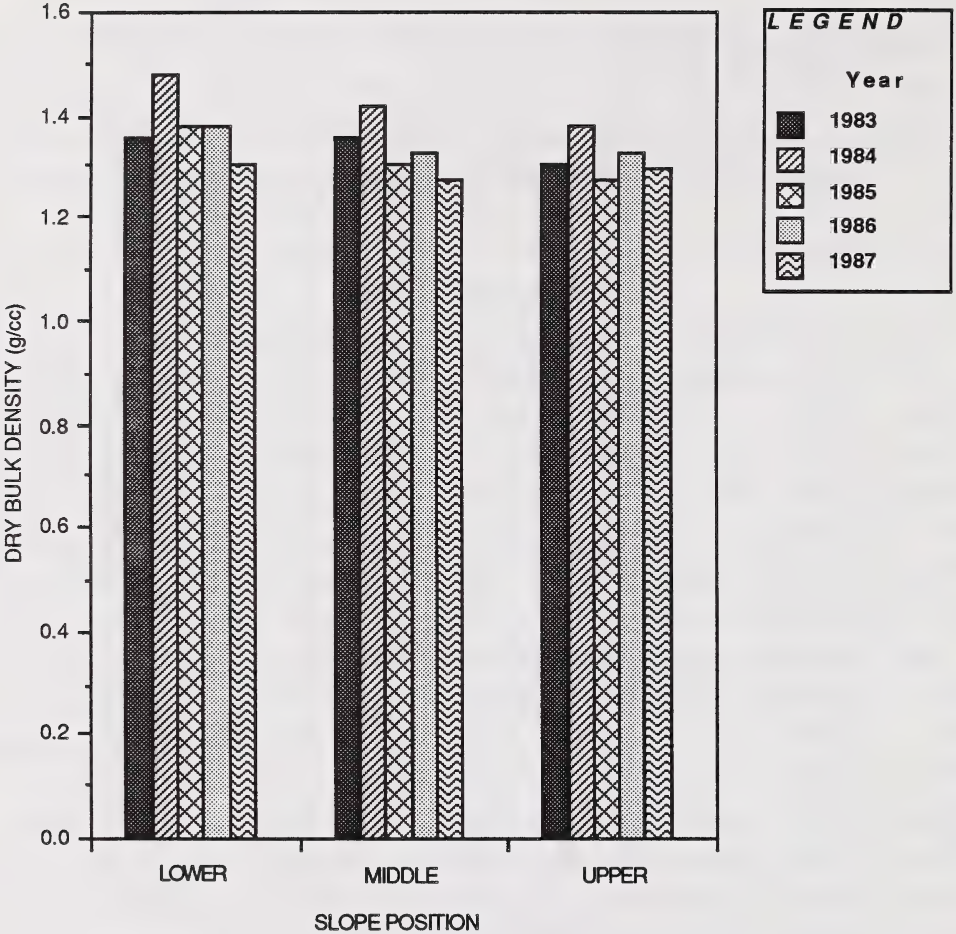


Figure 14. **Comparison of soil dry bulk density (g/cc) between years within slope positions for the effective subsoil root zone - slope experiment.**

Table 31. Comparison of soil EC_e between slope types within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Slope Type (Aspect x Slope)		1982	1983	1984	1985	1986	1987	6 Year Mean
		Electrical Conductivity[a] (mS/cm)						
		Lower Slope (n=6)						
North	5°	0.4a	0.7a	0.6a	0.8a	0.5a	0.5a	0.6a
	10°	0.4a	0.6a	0.5a	0.5a	0.6a	0.4a	0.5a
South	5°	0.5a	0.6a	0.7a	0.8a	1.0a	0.5a	0.7a
	10°	0.4a	0.6a	0.5a	0.7a	0.5b	0.5a	0.6a
S.E.		0.1	0.1	0.2	0.2	0.1	0.1	0.1
		Mid Slope (n=6)						
North	5°	0.4a	0.6ab	0.4a	0.6a	0.8a	0.5a	0.6ab
	10°	0.4a	0.9a	0.3a	0.6a	0.4a	0.5ab	0.5b
South	5°	0.5a	0.7ab	1.1a	1.0a	0.5a	0.4ab	0.7a
	10°	0.5a	0.5b	0.4a	0.5a	0.4a	0.4b	0.4b
S.E.		0.1	0.1	0.3	0.3	0.2	0.1	0.1
		Upper Slope (n=6)						
North	5°	0.6a	0.7a	1.0a	1.0a	0.6a	0.5a	0.7a
	10°	0.4a	0.7a	0.4a	0.7a	0.5a	0.4a	0.5a
South	5°	0.6a	0.8a	0.5a	0.9a	0.5a	0.5a	0.6a
	10°	0.4a	0.9a	0.5a	0.5a	0.6a	0.5a	0.6a
S.E.		0.1	0.4	0.4	0.3	0.2	0.1	0.1

[a] Means down the same column (within subtables) followed by the same letter are not signficantly different at the 5% level (Duncan's multiple comparison of means).

Table 32. Comparison of Na between slope types within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Slope Type (Aspect x Slope)		Year 1982	1983	1984	1985	1986	1987	6 Year Mean
		Soluble Sodium[a] (me/L)						
		Lower Slope (n=6)						
North	5°	1.1a	2.8a	2.2a	5.7a	2.9b	2.9a	2.9a
	10°	0.9a	2.4a	1.9a	2.0a	3.3b	1.9a	2.0a
South	5°	1.0a	2.6a	3.8a	4.4a	6.1a	3.4a	3.6a
	10°	0.7a	2.5a	2.2a	4.0a	2.8b	3.1a	2.6a
S.E.		0.5	0.8	1.8	1.6	1.0	1.0	0.8
		Mid Slope (n=6)						
North	5°	0.6a	2.2a	1.2a	2.9a	4.7a	3.1a	2.4a
	10°	0.4a	3.1a	0.7a	2.1a	1.7a	2.2ab	1.7a
South	5°	0.8a	2.7a	2.7a	4.4a	2.9a	2.0ab	2.6a
	10°	1.2a	1.2a	1.5a	2.1a	1.7a	1.3b	1.5a
S.E.		0.5	1.0	1.3	1.9	1.6	0.6	0.8
		Upper Slope (n=6)						
North	5°	1.3a	2.6a	7.4a	6.2a	3.2a	2.5a	3.8a
	10°	0.7a	2.7a	1.3a	3.5a	3.0a	2.5a	2.3a
South	5°	1.5a	3.6a	2.5a	5.9a	3.3a	3.0a	3.3a
	10°	1.0a	6.1a	1.9a	2.7a	4.0a	2.5a	3.0a
S.E.		0.5	3.6	4.2	3.1	1.5	0.9	1.0

[a] Means down the same column (within subtables) followed by the same letter are not signficantly different at the 5% level (Duncan's multiple comparison of means).

Table 33. Comparison of SAR between slope types within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Slope Type (Aspect x Slope)		Year 1982	1983	1984	1985	1986	1987	6 Year Mean
		Lower Slope[a] (n=6)						
North	5°	0.8	2.0	1.6	4.1	2.4	2.8	2.3
	10°	0.6	1.8	1.5	1.5	2.9	1.8	1.7
South	5°	0.7	2.0	3.0	3.2	4.6	3.3	2.8
	10°	0.5	1.9	1.7	3.0	2.3	2.9	2.1
S.E.		0.4	0.6	1.4	1.2	0.9	1.2	0.7
		Mid Slope (n=6)						
North	5°	0.4	1.5	1.0	2.2	3.8	2.6	1.9
	10°	0.3	1.8	0.6	1.5	1.4	1.9	1.2
South	5°	0.6	2.0	1.5	2.4	2.4	1.7	1.7
	10°	1.0	0.9	1.2	1.6	1.5	1.2	1.2
S.E.		0.4	0.6	0.7	1.2	1.3	0.6	0.5
		Upper Slope (n=6)						
North	5°	0.9	1.7	4.2	5.0	2.8	2.1	2.8
	10°	0.6	1.9	1.0	2.7	2.6	2.4	1.9
South	5°	1.1	2.6	2.3	4.0	3.0	2.9	2.7
	10°	0.8	5.3	1.5	2.0	3.7	2.2	2.6
S.E.		0.4	3.0	2.2	2.4	1.3	0.7	0.8

[a] There were no significant differences in SAR values between treatments within slope positions.

Table 34. Comparison of soil EC_e between slope positions within slope types for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Slope Position	Year 1982	1983	1984	1985	1986	1987	6 Year Mean
	Electrical Conductivity[a] (mS/cm)						
	North 5° Treatment (n=6)						
Lower	0.4a	0.7a	0.6a	0.8a	0.5a	0.5a	0.6a
Middle	0.4a	0.6a	0.4a	0.6a	0.8a	0.5a	0.6a
Upper	0.6a	0.7a	1.0a	1.0a	0.6a	0.5a	0.7a
S.E.	0.1	0.1	0.5	0.3	0.1	0.1	0.1
	North 10° Treatment (n=6)						
Lower	0.4a	0.6a	0.5a	0.5a	0.6a	0.4a	0.5a
Middle	0.4a	0.9a	0.3a	0.6a	0.4a	0.5a	0.5a
Upper	0.4a	0.7a	0.4a	0.7a	0.5a	0.4a	0.5a
S.E.	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	South 5° Treatment (n=6)						
Lower	0.5a	0.6a	0.7a	0.8a	1.0a	0.5a	0.7a
Middle	0.5a	0.7a	1.1a	1.0a	0.5b	0.4a	0.7a
Upper	0.6a	0.8a	0.5a	1.0a	0.5b	0.5a	0.6a
S.E.	0.1	0.2	0.3	0.5	0.1	0.1	0.1
	South 10° Treatment (n=6)						
Lower	0.4a	0.6a	0.5a	0.7a	0.5a	0.5a	0.6a
Middle	0.4a	0.5a	0.4a	0.5a	0.4a	0.4a	0.4a
Upper	0.4a	0.9a	0.5a	0.5a	0.6a	0.5a	0.6a
S.E.	0.1	0.5	0.1	0.2	0.1	0.1	0.1

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

Table 35. Comparison of Na between slope positions within slope types for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Slope Position	Year 1982	1983	1984	1985	1986	1987	6 Year Mean
			Soluble Sodium[a] (me/L)				
			North 5° Treatment (n=6)				
Lower	1.1a	2.8a	2.2a	5.7a	2.9a	2.9a	2.9a
Middle	0.6a	2.2a	1.2a	2.9a	4.7a	3.1a	2.4a
Upper	1.3a	2.6a	7.4a	6.1a	3.2a	2.5a	3.8a
S.E.	0.4	0.9	5.1	3.4	1.0	1.0	0.9
			North 10° Treatment (n=6)				
Lower	0.9a	2.4a	1.9a	2.0a	3.3a	1.9a	2.0a
Middle	0.4a	3.1a	0.7a	2.1a	1.7b	2.2a	1.7a
Upper	0.7a	2.7a	1.3a	3.5a	3.0a	2.5a	2.3a
S.E.	0.4	1.1	0.5	1.4	0.5	0.4	0.4
			South 5° Treatment (n=6)				
Lower	1.0a	2.6a	3.8a	4.4a	6.1a	3.4a	3.6a
Middle	0.8a	2.7a	2.7a	4.4a	2.9a	2.0a	2.6a
Upper	1.5a	3.6a	2.5a	5.9a	3.3a	3.0a	3.3a
S.E.	0.3	1.3	1.7	3.0	0.8	1.1	0.8
			South 10° Treatment (n=6)				
Lower	0.7a	2.5a	2.2a	4.0a	2.8a	3.1a	2.6a
Middle	1.2a	1.2a	1.5a	2.1a	1.7a	1.3a	1.5a
Upper	1.0a	6.1a	1.9a	2.7a	4.0a	2.5a	3.0a
S.E.	0.5	4.2	0.7	1.5	1.3	0.8	1.0

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

Table 36. Comparison of SAR between slope positions within slope types for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Slope Position	Year 1982	1983	1984	1985	1986	1987	6 Year Mean
	North 5° Treatment[a] (n=6)						
Lower	0.8a	2.0a	1.6a	4.1a	2.4a	2.8a	2.3a
Middle	0.4a	1.5a	1.0a	2.2a	3.8a	2.6a	1.9a
Upper	0.9a	1.7a	4.2a	5.0a	2.8a	2.1a	2.8a
S.E.	0.3	0.7	2.7	2.7	1.0	1.0	0.7
	North 10° Treatment (n=6)						
Lower	0.6a	1.9a	1.5a	1.5a	2.9a	1.8a	1.7a
Middle	0.3a	1.8a	0.6b	1.5a	1.4b	1.9a	1.2a
Upper	0.6a	1.9a	1.0ab	2.7a	2.6a	2.4a	1.9a
S.E.	0.3	0.7	0.3	1.1	0.4	0.4	0.3
	South 5° Treatment (n=6)						
Lower	0.7a	2.0a	3.0a	3.2a	4.6a	3.3a	1.7a
Middle	0.6a	2.0a	1.5a	2.4a	2.4a	1.7a	2.8a
Upper	1.1a	2.6a	2.3a	4.0a	3.0a	2.9a	2.7a
S.E.	0.2	0.9	1.2	1.5	0.6	1.1	0.6
	South 10° Treatment (n=6)						
Lower	0.5a	1.9a	1.7a	3.0a	2.3a	2.9a	2.1a
Middle	1.0a	0.9a	1.2a	1.6a	1.5a	1.2a	1.2a
Upper	0.8a	5.3a	1.5a	2.0a	3.7a	2.2a	2.6a
S.E.	0.4	3.6	0.6	1.1	1.2	0.7	0.9

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

subsoil/minespoil contact has been summarized in Table 37 and Figure 15. The data show that there has been some fluctuation in EC_e levels above the contact since 1982, but there has been no trend toward increasing or decreasing EC_e levels over time.

Changes in soluble Na and SAR levels between years within slope positions for the 15 cm increment above the subsoil/minespoil contact have been summarized in Tables 38 and 39 and Figures 16 and 17. The mean data across all slope types show a significant increase in soluble Na and SAR at the lower and mid slope positions from 1982 to 1983. A similar trend in increasing soluble Na and SAR levels was observed at the upper slope position across all slope types. Individual slope types showed a general increase in soluble sodium and SAR levels from 1982 to 1983, but these increases were not always significant. Soluble Na and SAR values from 1983 to 1987 were variable, but showed an increasing trend over time. Increases in SAR above the subsoil/minespoil contact were significant over the six year monitoring period for the 5° North and 10° South treatments at the lower slope position, and 5° and 10° North treatments at the mid slope position.

Table 37. Comparison of soil EC_e between years within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Year	North 5°	North 10°	South 5°	South 10°	Mean
	Slope Type (Aspect x Slope)				
		Electrical Conductivity[a] (mS/cm)			
		Lower Slope (n=6)			
1982	0.4b	0.4bc	0.5b	0.4b	0.4c
1983	0.7ab	0.6a	0.6ab	0.6ab	0.6ab
1984	0.6ab	0.5ab	0.7ab	0.5ab	0.6ab
1985	0.8a	0.5ab	0.8ab	0.7a	0.7a
1986	0.5b	0.6a	1.0a	0.5ab	0.7a
1987	0.5b	0.4bc	0.5b	0.5ab	0.5bc
S.E.	0.1	0.1	0.2	0.1	0.1
		Mid Slope (n=6)			
1982	0.4b	0.4b	0.5a	0.4a	0.4b
1983	0.6ab	0.9a	0.7a	0.5a	0.7a
1984	0.4b	0.3b	1.1a	0.4a	0.6ab
1985	0.6ab	0.6b	1.0a	0.5a	0.7a
1986	0.8a	0.4b	0.5a	0.4a	0.5ab
1987	0.5ab	0.5b	0.4a	0.4a	0.4b
S.E.	0.1	0.1	0.3	0.1	0.1
		Upper Slope (n=6)			
1982	0.6a	0.4bc	0.6a	0.4a	0.5a
1983	0.7a	0.7a	0.8a	0.9a	0.8a
1984	1.0a	0.4bc	0.5a	0.5a	0.6a
1985	1.0a	0.7a	0.9a	0.5a	0.8a
1986	0.6a	0.5ab	0.5a	0.6a	0.6a
1987	0.5a	0.4bc	0.5a	0.5a	0.5a
S.E.	0.4	0.1	0.2	0.3	0.2

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means). EC_e values rounded to one decimal point.

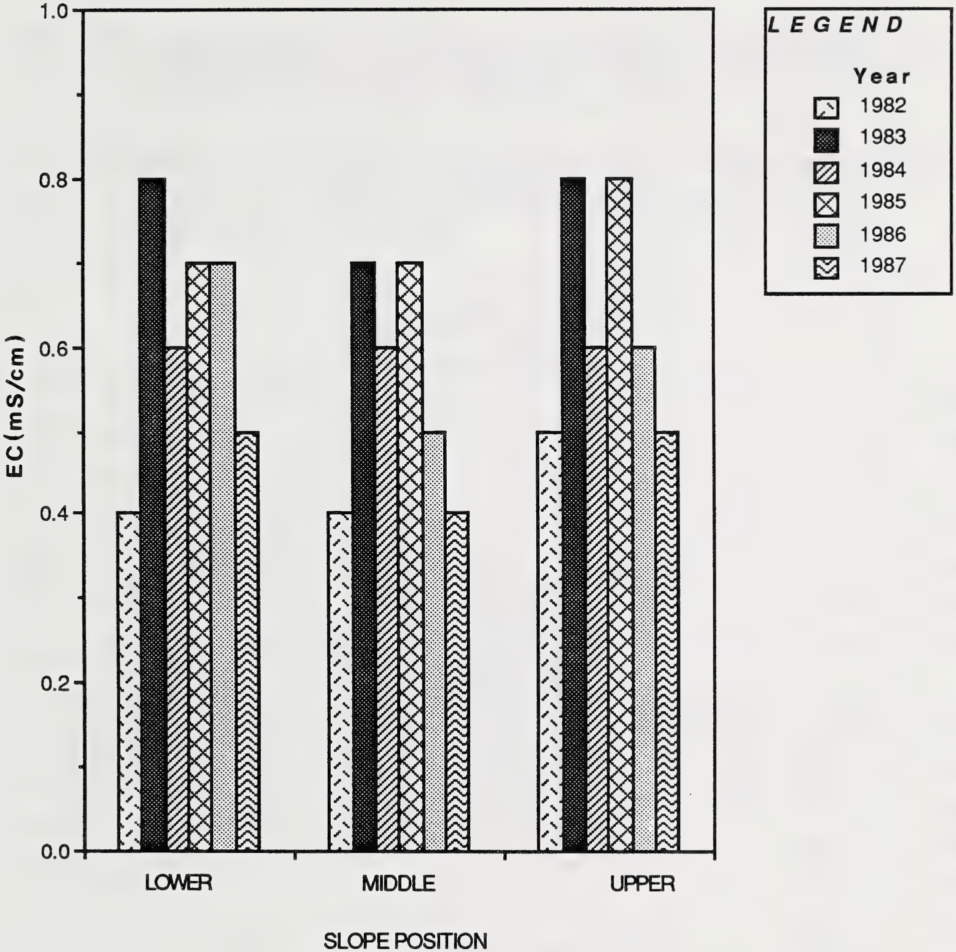


Figure 15. Comparison of soil EC (mS/cm) between years within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Table 38. Comparison of Na between years within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Year	North 5°	North 10°	South 5°	South 10°	Mean
	Slope Type (Aspect x Slope)				
		Soluble Sodium[a] (me/L)			
		Lower Slope (n=6)			
1982	1.1b	0.9a	1.0a	0.7b	0.9c
1983	2.8b	2.4a	2.6a	2.5ab	2.6b
1984	2.2b	1.9a	3.8a	2.2ab	2.5b
1985	5.7a	2.0a	4.4a	4.0a	4.0a
1986	2.9b	3.3a	6.1a	2.8ab	3.8ab
1987	2.9b	1.9a	3.4a	3.1ab	2.8ab
S.E.	1.1	0.6	1.3	1.0	0.6
		Mid Slope (n=6)			
1982	0.6b	0.4b	0.8a	1.2a	0.7c
1983	2.2ab	3.1a	2.7a	1.2a	2.3ab
1984	1.2b	0.7b	2.7a	1.5a	1.5bc
1985	2.9ab	2.1ab	4.4a	2.1a	2.9a
1986	4.7a	1.7ab	2.9a	1.7a	2.8a
1987	3.1ab	2.2ab	2.0a	1.3a	2.1ab
S.E.	1.0	0.7	1.3	0.9	0.5
		Upper Slope (n=6)			
1982	1.3a	0.7b	1.5b	1.0a	1.1a
1983	2.6a	2.7ab	3.6ab	6.1a	3.7a
1984	7.4a	1.3ab	2.5ab	1.9a	3.3a
1985	6.2a	3.5a	5.9a	2.7a	4.5a
1986	3.2a	3.0ab	3.3ab	4.0a	3.4a
1987	2.5a	2.5ab	3.0ab	2.5a	2.6a
S.E.	4.2	1.0	1.8	2.8	1.3

[a] Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

Table 39. Comparison of SAR between years within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

Year	North 5°	North 10°	South 5°	South 10°	Mean
	Slope Type (Aspect x Slope)				
	Lower Slope (n=6)				
1982	0.8c*	0.6a	0.7a	0.5b	0.7c
1983	2.0bc	1.9a	2.0a	1.9ab	2.0b
1984	1.6bc	1.5a	3.0a	1.7ab	2.0b
1985	4.1a	1.5a	3.2a	3.0a	3.0a
1986	2.4abc	3.0a	4.6a	2.3a	3.1a
1987	2.8ab	1.8a	3.3a	2.9a	2.7ab
S.E.	0.8	0.4	0.9	0.8	0.4
	Mid Slope (n=6)				
1982	0.4c	0.3c	0.6a	1.0a	0.6c
1983	1.5bc	1.8a	2.0a	0.9a	1.6ab
1984	1.0bc	0.6bc	1.5a	1.2a	1.1bc
1985	2.2abc	1.5ab	2.4a	1.6a	1.9a
1986	3.8a	1.4ab	2.4a	1.5a	2.3a
1987	2.6ab	1.9a	1.7a	1.2a	1.8a
S.E.	0.8	0.4	0.7	0.7	0.3
	Upper Slope (n=6)				
1982	1.0a	0.6b	1.1b	0.8a	0.8a
1983	1.7a	1.9ab	2.6ab	5.3a	2.9a
1984	4.2a	1.0ab	2.3ab	1.5a	2.3a
1985	5.0a	2.7a	4.0a	2.0a	3.4a
1986	2.8a	2.6a	3.0ab	3.7a	3.0a
1987	2.1a	2.4ab	2.9ab	2.2a	2.4a
S.E.	2.7	0.8	1.0	2.4	1.0

* Means down the same column (within subtables) followed by the same letter are not significantly different at the 5% level (Duncan's multiple comparison of means).

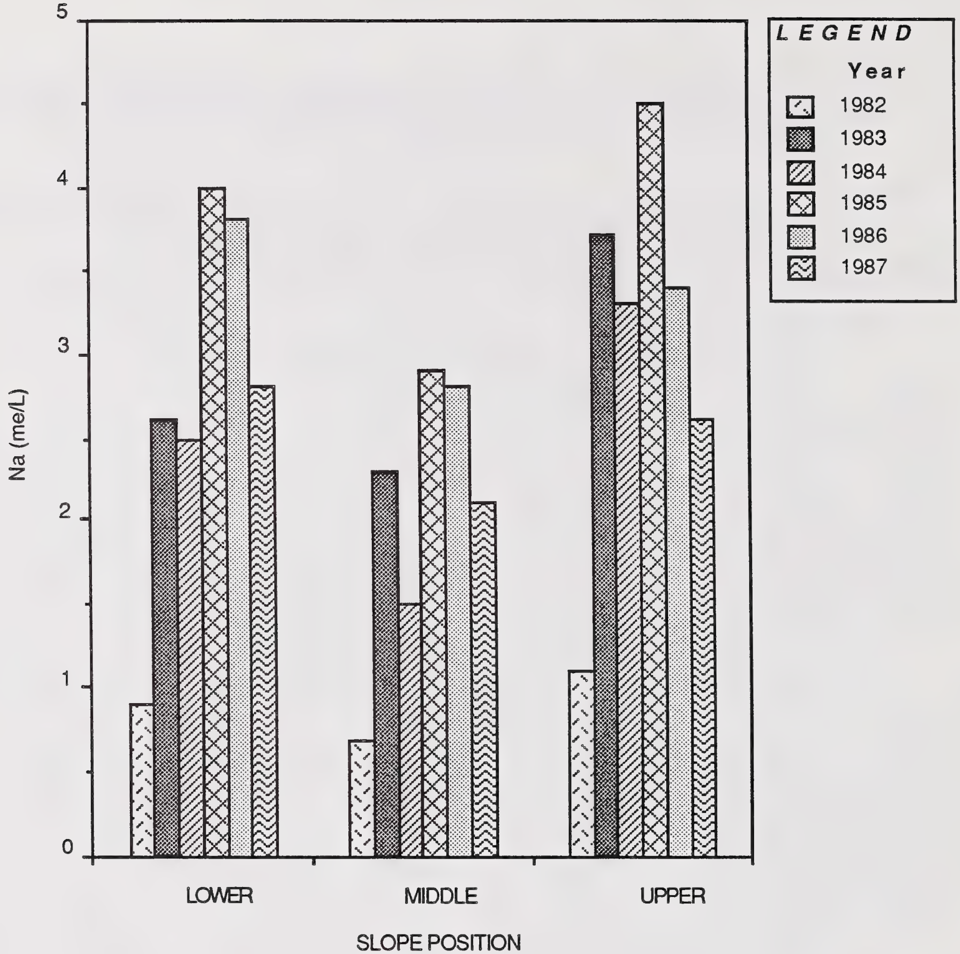


Figure 16. Comparison of Na (me/L) between years within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.

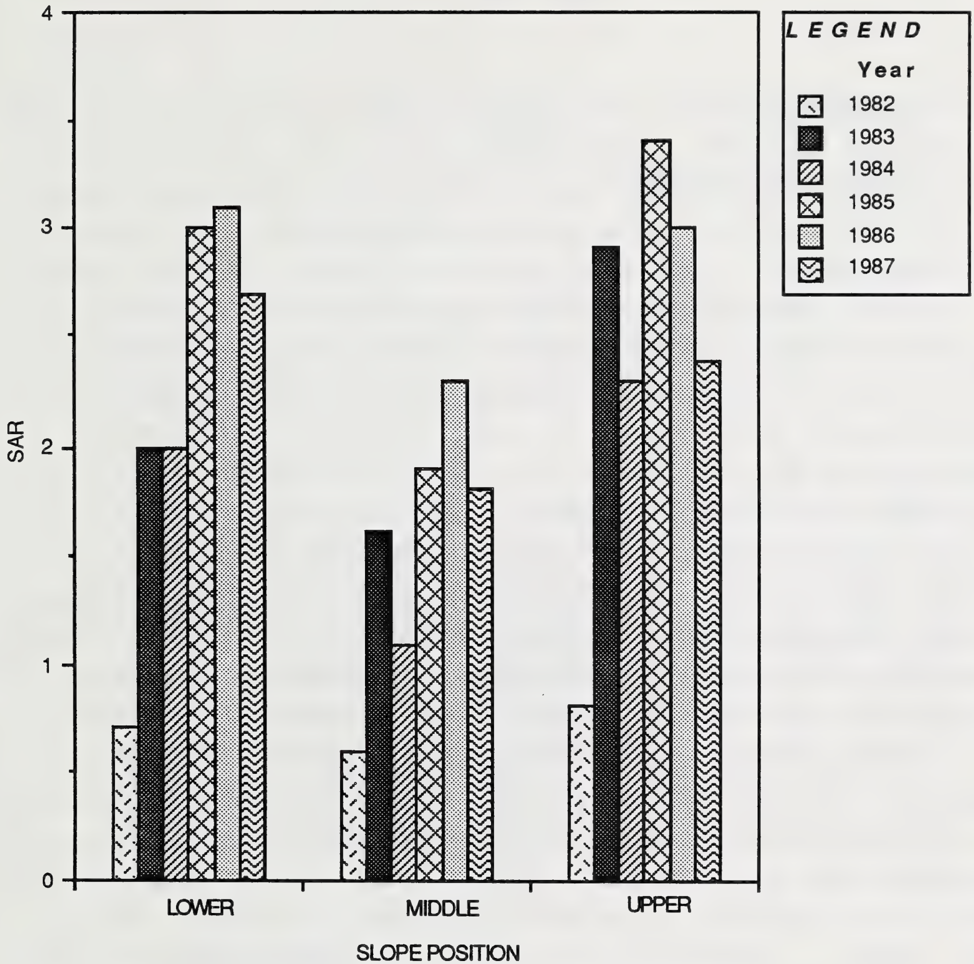


Figure 17. **Comparison of SAR between years within slope positions for the 15 cm increment immediately above the subsoil/minespoil contact - slope experiment.**

4. DISCUSSION

4.1 SUBSOIL DEPTH EXPERIMENT

4.1.1 Crop Yield

Results show an increase in forage and barley (grain) yield with increasing subsoil thickness from 0.00 m to 0.55 m. Optimum forage and barley yields appear to have been achieved when at least 0.95 m of subsoil was replaced. No significant gain in yield was apparent when more than 0.95 m (i.e. 1.35, 1.85 or 3.45 m) of subsoil was replaced over sodic minespoil. There was no significant difference associated with the increase in barley or forage yield between the 0.55 and 0.95 m subsoil treatments (95% confidence), but there was a consistent trend toward increasing yield. A high degree of sample variability between a small number of replicates appears to have been partly responsible for the lack of significance.

Forage yields were more consistent from year to year than barley yields. This was attributed in part to the development of a deep, extensive root system under the perennial forage crop compared to the shallow root system under the annual barley crop. Deep roots encourage crop tolerance to seasonal occurrences of drought and moisture stress. Examination of precipitation data (Figure 4) indicated that April rainfall levels were instrumental in determining cereal crop yields, particularly in 1984 (lowest yield) and 1985 (highest yield).

Ten year average forage yields reported for hay crops in Agricultural Reporting Area #5 (Census Division 8 and 11) were 4.7 t/ha (470 g/m^2). Barley (grain) yields reported for crops in Census Division 11 were 2.3 t/ha (230 g/m^2). The subsoil depth experiment data compare favourably with the 10 year averages. Forage yields were 483 g/m^2 in 1984; 524 g/m^2 in 1985; 473 g/m^2 in 1986; and 486 g/m^2 in 1987 on the 0.55 m treatment. It should be noted the above forage yields were measured on an oven dry basis and therefore

are potentially about 10% lower than comparable values reported by the Statistics Branch of Alberta Agriculture. From a practical standpoint, however, these yields should be considered directly comparable due to reduced harvest losses and lower cutting height of sampled vegetation compared to government averages. Barley (grain) yields were 284 g/m^2 in 1983; 149 g/m^2 in 1984; 401 g/m^2 in 1985; 305 g/m^2 in 1986; and 250 g/m^2 in 1987 on the subsoil depth experiment 0.55 m treatment. All grain was graded as No. 1 Feed.

4.1.2 Root Depth

Results show a consistent increase in root depth as subsoil thickness increased, especially under forage. The data show that forage had a deeper root zone than barley and deeper penetration into subsoil and minespoil material. Therefore, forage has more potential to increase organic matter content and soil fertility levels within the root zone, reduce bulk density within compacted soils, improve infiltration rates into minespoil and reduce accumulations of soil moisture above the subsoil/minespoil contact (by either extracting moisture from this contact zone or by aiding moisture movement into the minespoil).

4.1.3 Soil Moisture

Soil moisture under forage was consistently reduced above the minespoil contact in the 0.55, 0.95 and 1.35 m subsoil treatments. The minespoil contact for all three treatments falls within the root zone of forage. Soil moisture under barley was not reduced above the contact in any subsoil treatment. However, there was a trend toward reduced moisture levels above the subsoil/minespoil contact in the 0.55 m treatment, which falls within the root zone of barley. Soil moisture profiles and root observations indicated that the effective root zone under forage extended to about 1.85 m by 1987. The effective root zone under barley extended to about 0.85 m.

Soil moisture above the subsoil/minespoil contact was observed to be lower under forage than barley in the 0.55, 0.95, 1.35

and 1.85 m subsoil treatments by 1987. There was essentially no change in soil moisture levels above the subsoil/minespoil contact in the 3.45 m treatment under either crop. The data suggest that higher consumptive use of available soil moisture by forages resulted in a reduction in soil moisture above the contact. In addition, penetration of sodic minespoil by forage roots may have contributed to a reduction in soil moisture above the contact by improving infiltration rates. Accumulations of soil moisture resulting from lower moisture consumption under barley have the potential to reduce surface trafficability, as well as increase upward migration of sodium from sodic spoil through the processes of diffusion and convection.

Results show that soil moisture above the subsoil/minespoil contact generally decreased over time under forage and increased over time under barley. These accumulations of soil moisture under cereal grain production could eventually result in the lateral transport of soluble sodium to low lying areas under undulating reconstructed topography and thereby produce sodic soils. The total soluble salt content of the minespoil is 1.9 mS/cm (relatively low). However, the SAR of this material is 20.1 (Table 1). Therefore, the main concern is the creation of sodic soils where this groundwater approaches the surface.

At present there is insufficient accurate data available to determine if a perched water table exists above the minespoil contact. Soil moisture profiles (Highvale Soil Reconstruction Reclamation Research Program Report, 1987) indicate that some soil moisture has migrated downward into the upper 15 cm of minespoil in the 1.35, 1.85 and 3.45 m treatments. This trend suggests the possibility of some internal drainage through the spoil material, thus reducing the potential for moisture buildup at the interface. Generally, a water table within 2 meters of the soil surface indicates a potential for the capillary rise of water and associated sodium to the soil surface and the eventual accumulation of salt, which in this case is sodium.

4.1.4 Soil Bulk Density

Bulk density within the effective root zone generally decreased over time under forage, but tended to increase under barley. The data indicated that forages would be more beneficial in reducing the bulk density of a compacted post reclamation soil than barley. A decrease in bulk density should contribute to improved moisture infiltration and root penetration into the subsoil.

4.1.5 Soil Chemistry

Results show that EC_e values remained low and did not change between subsoil thicknesses, crops or years. There does not appear to be any concern regarding salinization of subsoil replacement material used in this experiment.

Results show that soluble Na and SAR values were elevated above the contact to some degree, but were variable and inconsistent when comparisons were made between subsoil thicknesses or crops. This was likely due to the variability in soil chemistry within the minespoil material itself. However, results did indicate an increase in Na and SAR above the contact during the first year (1983) of crop growth. Data from the 1987 interim report (Monenco 1988) showed that the increase was concentrated primarily within the 15 cm increment immediately above the subsoil/minespoil contact. There was a similar increase in Na and SAR within topsoil overlying minespoil in the 0.00 m subsoil treatment. It appears that once an equilibrium in Na and SAR was reached in 1984, values fluctuated from year to year and showed no consistent trend. Concern has been raised that contamination by minespoil material has occurred during sampling of the upper 15 cm of subsoil. No absolute assurance can be given that this did not occur. However, the two materials are distinctly different in appearance, and extreme care was taken during sampling.

It was not known if additional upward migration or downward flushing of salts with more precipitation would occur over a greater time period. The accumulation of soil moisture observed above the

subsoil/minespoil contact under barley has the potential to increase upward migration of sodium by chemical diffusion and convection if moist soil conditions were to persist.

4.2 SLOPE EXPERIMENT

4.2.1 Crop Yield

Over the 5 year study period, there was a trend toward higher forage yields on north aspects and 5° slopes compared to south aspects and 10° slopes. Less direct sunlight exposure, lower surface temperatures and decreased evapotranspiration rates were likely responsible for the higher yield on north facing slopes. Decreased soil moisture infiltration and increased surface runoff on the steeper slope may have decreased yields.

Forage establishment at the lower slope position appeared to be less successful than at the upper and mid slope positions. Mean forage yields from lower slope positions were significantly lower than those reported for mid slope and upper slope positions during the first two to three years of crop growth. The lower yields on the lower slope position could be attributed to more compaction as a result of vehicle traffic during plot construction (see Section 4.2.3).

Forage yields during the establishment year (1983) were lower than in subsequent years as expected and were likely reduced further by the lack of precipitation in 1983. Yields increased from 1984 to 1986, when maximum forage yields were attained for all treatments and all slope positions, and coincided with highest seasonal precipitation during the study period. By 1986, productivity at the lower slope position was equivalent to forage production levels reported for mid and upper slope positions within the same slope types. These comparative yields were retained in 1987 for all slope types except 5° South, where yields at the lower slope position were lower than corresponding middle and upper slope positions.

Ten year average forage yields reported for hay crops in Agricultural Reporting Area #5 (Census Division 8 and 11) were 4.7 t/ha (470 g/m^2). The slope experiment data compares favourably with the 10 year average. Slope plot yields averaged 421 g/m^2 in 1984, 499 g/m^2 in 1985, 597 g/m^2 in 1986 and 521 g/m^2 in 1987 across all treatments and subplots.

4.2.2 Soil Moisture

There were no consistent trends in soil moisture content above the subsoil/minespoil contact with respect to slope position or slope type. However, highest soil moisture content was usually associated with the lower slope position. Lowest soil moisture content was generally associated with the 10° treatments in the upper slope positions. At the upper slope position the 10° South treatment was drier above the subsoil/minespoil contact than other slope types.

The most apparent soil moisture change occurred with respect to time. Soil moisture content above the subsoil/minespoil contact decreased from 1983 to 1987 by 13, 20 and 18% in the lower, mid and upper slope positions, respectively. Forage crops grown on 55 cm of subsoil overlying sodic minespoil appear to prevent downslope migration of significant quantities of soil moisture. Saturated soil conditions have not been physically observed or measured at any slope position or monitored soil profile depth during 5 years of soil moisture monitoring. Higher moisture conditions in lower slope positions were probably due to less evapotranspiration (lower productivity) and some accumulation of surface runoff.

4.2.3 Soil Bulk Density

Mean soil bulk densities decreased over time within the subsoil root zone at the lower and mid slope positions. The trend toward decreasing soil bulk densities was common to all slope types over the five year monitoring period. Soil bulk densities within the

root zone at the upper slope position did not change and showed little or no declining trend.

Lower and mid slope positions received more traffic during plot construction because the plots were built from the lower slope and soil material was pushed upward. The extensive root system of the forage crop appears to have decreased soil bulk density in these heavy traffic lower slope areas since plot construction. Upper slope soil bulk densities in 1983 were equivalent to bulk densities measured in the root zone of lower and mid slope positions in 1987. This indicates that soil bulk density may have stabilized after five years, as evidenced by declining bulk density levels in more compacted soils (lower and mid slope position) compared to no change on upper slope positions.

4.2.4 Soil Chemistry

Baseline soil chemistry sampling and analysis was initiated shortly after plot construction in 1982. Since that time, topsoil quality has changed very little with respect to measured parameters such as reaction (pH), salinity and sodicity. Topsoil across all treatments can be rated as "good" quality material for soil replacement (Alberta Agriculture 1987). Subsoil quality remains "good to fair" with respect to pH and "good" with respect to salinity and sodicity across all treatments (Monenco Consultants Ltd. 1988).

Since 1982, soil chemistry data have indicated that chemical property changes have been restricted to the 0 to 15 cm increment and to a lesser extent the 15 to 30 cm increment above the subsoil/minespoil contact. Any changes in soil EC_e, soluble Na and SAR values have occurred within this zone. However, the magnitude of these changes has been minimal. Electrical conductivity above the subsoil/minespoil contact has fluctuated between years, but has never exceeded 1.1 mS/cm in any slope type or slope position. The subsoil/minespoil contact zone, especially in the lower slope position, has remained unsalinized after five years of forage crop growth.

Soluble Na and SAR levels increased during the first year of crop growth (1983) and have shown an increasing trend since that time. Soluble Na and SAR levels appeared to increase within some slope types until 1985 and then decline, but this may have been due to the variability in soil chemistry inherant within the minespoil material itself. All reported mean Na values for the subsoil/minespoil contact were less than 6.1 me/L. Mean SAR values were 5.0 or less. The increases in soluble Na and SAR values from 1982 to 1983 may have been the result of two factors:

1. the soil chemical concentration gradient was greater during the initial period of material placement; and
2. the moisture content was greater in the early stages of the project (during forage crop establishment), which contributed toward an increase in upward migration of Na through mechanisms such as diffusion and convection.

5. CONCLUSIONS

5.1 SUBSOIL DEPTH EXPERIMENT

5.1.1 Crop Yield

- The null hypothesis that crop productivity on reclaimed sodic minespoil will not be a function of subsoil thickness (subsoil was defined as non-sodic soil material placed between spoil and replaced topsoil) was rejected; and
- The null hypothesis that forage and grain crops will not respond differently to varying subsoil thickness was accepted.

Forage and barley yields increased as subsoil thickness increased over sodic minespoil from 0.00 to 0.55 metres. Optimum forage and barley yields appeared to have been achieved with the replacement of at least 0.95 m of subsoil, but the yield difference between the 0.55 m and 0.95 m subsoil treatment was not significant. No significant increases in yield were measured on subsoil treatments greater than 0.95 m. Both forage and barley yields on the 0.55 m treatment compared favorably to ten year average yields for the undisturbed cropland surrounding the area. Forage yields were more consistent from year to year than barley yields, likely due to the deeper root system associated with perennial forages which would allow increased access to soil moisture during drought periods.

5.1.2 Soil Moisture

- The null hypothesis that the subsoil/minespoil interface will not interfere with the vertical movement of water was rejected.

Soil moisture levels above the subsoil/minespoil contact tended to decline over time under forage when the subsoil thickness was 1.85 m or less. The effective root zone extended to about 185 cm

under the forage crop. Soil moisture levels under barley did not change over time, although there was a decreasing trend in the 0.55 m treatment. The effective root zone extended to about 85 cm under the barley crop. Overall, bulk density and soil moisture levels were consistently higher under barley than forage. Higher soil moisture levels were attributed to the lower consumptive use of available soil moisture by barley compared to forage. Accumulations of soil moisture under barley have the potential to reduce surface trafficability and increase upward migration of sodium. Moisture probe and drill log data showed an accumulation of soil moisture above the subsoil/minespoil contact in the 0.55, 0.95, 1.35, 1.85 and 3.45 m treatments under cereals. Similar accumulations under forage were detected only in the 3.45 m treatment in 1987. Soil moisture profiles have indicated some moisture migration downward into the upper 15 cm of minespoil, suggesting the potential for development of internal drainage and reduced moisture buildup above the interface. The depth experiment showed that forage was better able to extract soil moisture from reconstructed subsoil than barley when the subsoil/minespoil contact was within the effective root zone.

5.1.3 Soil Chemistry

- o The null hypothesis that salts/sodium will not migrate from sodic minespoil into subsoil was rejected.

Soil EC_e values remained low and were not considered a detrimental factor in crop productivity. Soluble Na and SAR values were variable, but did show an increase above the subsoil/minespoil contact after the first year of crop growth. Sodium and SAR increases were most obvious within the 15 cm increment of subsoil or topsoil immediately above the minespoil contact. Levels decreased toward subsoil background conditions in the 15 to 30 cm increment above the subsoil/minespoil contact. There was no consistent trend in Na and

SAR values after 1984 above the subsoil/minespoil contact, so it was not known if upward migration would continue to occur over a longer time period or whether a soil chemical equilibrium has become quickly established.

5.2 SLOPE EXPERIMENT

5.2.1 Crop Yield

- o The null hypothesis that crop productivity will not be a function of slope position or slope steepness and aspect in the reclaimed landscape was rejected.

The forage yield data show north facing slopes to be more productive than south facing slopes and 5° slopes to be more productive than 10° slopes. The most productive treatment was 5° North. Forage yield at lower slope positions was generally less than yields at mid and upper slope positions, especially during the first two or three years after planting.

5.2.2 Soil Chemistry

- o The null hypothesis that downslope salt transport will be independent of slope and aspect (would occur on all slope types), was tentatively rejected (two of four slope types show accumulations in lower slope positions).

There has been little change in EC_e above the subsoil/minespoil contact since plot construction in 1982. Soluble Na and SAR levels increased at the subsoil/minespoil contact during the first year of crop growth, but showed no consistent trend over time after 1983. All soils were considered nonsaline, nonsodic and of good quality. SAR values above the subsoil/minespoil contact remain less than 3.5 after five years of forage production. Upward salt migration

from the sodic minespoil into the overlying subsoil did take place, but not to any critical degree. Forage crops appear to have inhibited salt migration by making efficient use of available soil moisture and thereby controlling an important vehicle for sodium transport. The slope experiment showed general increases in soluble sodium levels from 1982 to 1987 on all slope types, but these increases were not significant. Increases in SAR at the subsoil/minespoil contact were significant over a six year period for 5° North and 10° South treatments at the lower slope position and 5° and 10° North treatments at the mid slope position.

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